POPULAR

LECTURES ON ASTRONOMY.

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LECTURES ON ASTRONOMY.

BY THE LATE

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MEMBER OF THE INSTITUTE OF FRANCE, ETC.

TRANSLATED WITH NOTES BY

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BY THE

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TRANSLATOR'S PREFACE.

If any apology be necessary for adding to the numerous elementary works on Astronomy already existing in our language, another sanctioned by the name of Arago, the Translator of this little volume confidently rests his justification upon the excellence of its contents. These will be found characterised by remarkable clearness and simplicity in the exposition of leading principles and phenomena, a judicious abstinence from intricate details, and a frequent and enlivening use of discursive reasonings on mixed topics of astronomical and general science. Mathematical terms are very sparingly, and mathematical proofs are not at all, introduced into these Lectures: they will therefore be easily intelligible to readers acquainted with scarcely more of the nomenclature of science than is included in the vocabulary of ordinary life. Lest, however, any verbal difficulty should occur to the non-mathematical reader, I have given in the Appendix a short explanation of the nature of angles, sines, tangents, and so forth: to this he will do well to refer before entering upon the text.

The chief difficulty experienced by the beginner in Astronomy, arises from his slowness in apprehending the principles on which the circles of the sphere are projected on a plane sheet of paper. Hence, the diagrams in his book speak to him an unknown language, the signs they present not calling up in his mind the ideas corresponding to them in the mind of the author. To obviate this difficulty, the learner, as he reads the definition of each circle, should examine its position on the terrestial globe, imprint on his mind the relation of its plane to those of the other circles, and exercise his imagination to conceive on the one hand the infinite diminution of the ball representing the earth, on the other the infinite expansion of the circles. He should also trace these circles in idea on the great concave sphere. The pole-star and the zenith will indicate the position of the meridian, the equator is at right angles to the meridian, &c.

In the body of the work, the Translator has aimed at strict fidelity in rendering the author's language into English: the only particular in which he has thought himself at liberty to deviate from his original, is in the arrangement of the tabular matter, this being apparently not the production of M. Arago, but of the reporter or editor of his Lectures. Some of the French tables have been omitted, as inappropriate, others have been recast and enlarged; and pains have been taken throughout to correct the gross typographical errors of the French copy, particularly manifest in all the numerical matter.

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POPULAR LECTURES ON ASTRONOMY.

LECTURE I.

REFLECTION AND REFRACTION OF LIGHT, GENERAL LAWS OF—LENSES—TELESCOPES, REFLECTING AND REFRACTING—STRUCTURE OF THE EYE.

Before entering on the immediate subject of Astronomy, it is well that we should become acquainted with the instruments with which Optics have furnished this science, and by which they have enabled it to make such progressive strides; instruments whose power has so extended the range of our senses, as in some measure to bring the universe within their scope. The study of these instruments will constitute the business of this first lecture.

There are two classes of telescopes, called, from the principles on which their construction is respectively based, *reflecting* and *refracting*: let us therefore, in the first instance, examine these two grand properties of light.

General Laws of the Reflection of Light.

If we cause a ray of solar light to fall obliquely on a polished surface, we mark the following resulting phenomena.

1. A part of the luminous ray is reflected in a certain direction, and if the eye be placed somewhere in the line of that direction, it will perceive an image of the sun in the line of the reflected ray carried backwards from the point of reflection.

2. The point where the incident ray meets the polished surface is visible in every direction; but it appears incomparably less brilliant if seen in any other direction than that of the reflected ray, the only one which gives a regular image of the sun.

3. A portion of the incident light escapes from reflection, and passes through the substance of the plane, if it be transparent, in obedience to fixed laws of which we shall speak hereafter. If the body on which the ray falls is opaque, this portion of light is absorbed.

Thus we have before us three very distinctive phenomena; one portion of the incident light is regularly reflected in a special direction; another is reflected indifferently in all directions, and disseminated as if the body on which it falls were not polished; lastly, the remainder passes through, or is absorbed.

Now then to investigate the direction followed by the portion regularly reflected,—We find,

1. *That the incident and the reflected ray lie both in one plane perpendicular to the reflecting surface.*

2. *That the incident and the reflected ray always form equal angles with the reflecting surface*; or in other words, *that the angle of reflection and the angle of incidence are equal.*

Such are the two general laws of reflection, from which we shall easily derive an explanation of the formation of images in this way.

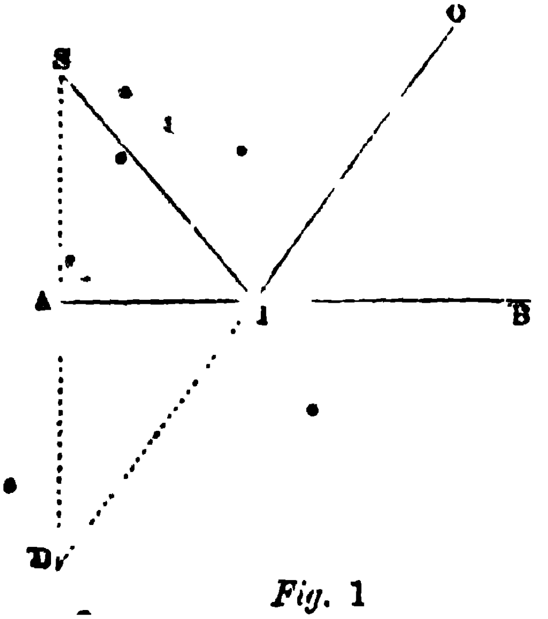

Fig. 1

Let us first take the case of a flat mirror: let S be a radiant point, O the eye of an observer, and A B the plane of the reflector. Amongst all the luminous rays issuing from S there will be one, S I for instance, which, after having been reflected from the mirror, will go and meet the eye at O, taking the direction IO, and thus making the angle of incidence equal to that of reflection. From the radiant point S let us draw SA perpendicular to the reflecting surface, and produce this line on the other side of the mirror, so that AD may be equal to SA; then from the point D let us draw the line DO to the eye; DO will be the direction of the reflected ray, and the point I, where it cuts the surface of the mirror, will be the point of incidence. Moreover, if the luminous object and the eye be supposed to be mathematical points without sensible dimensions, the ray determined in the preceding manner is the only one that can be reflected towards the eye.

But the opening of the pupil, which admits the rays of light, is not a mathematical point, but a space, the diameter of which in man is about 2-25ths of an inch, and which we may represent by LL. All the reflected rays then that find entrance through this opening will arrive at the retina, and contribute to vision. Now each of these rays may be determined by the same construction that we have just employed; whence it is evident that they will form a cone with a circular base, the point of which is at D, and the base at LL. It is a known fact that the eye, when it can judge freely of the distances of luminous points, always supposes them situated in the point from whence the rays that fall upon the eye seem to diverge. Thus the eye being placed at O, the luminous point will appear to it, when seen by reflection, to be

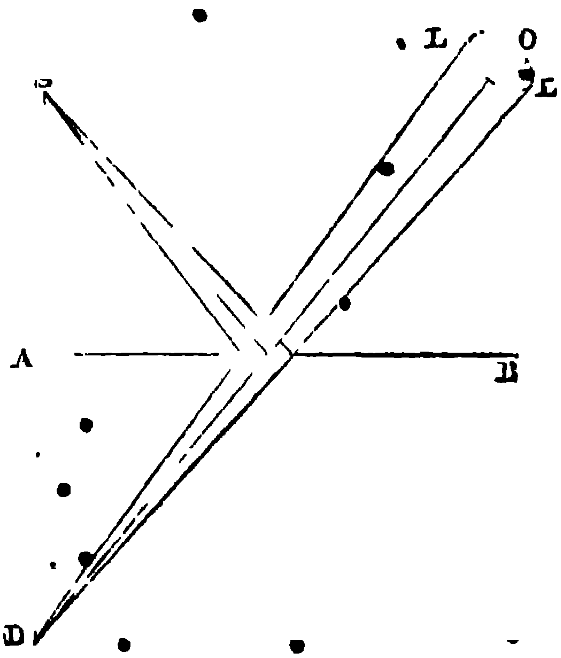

Fig. 2.

situated at D, that is to say, as much behind the mirror as it is actually before it.

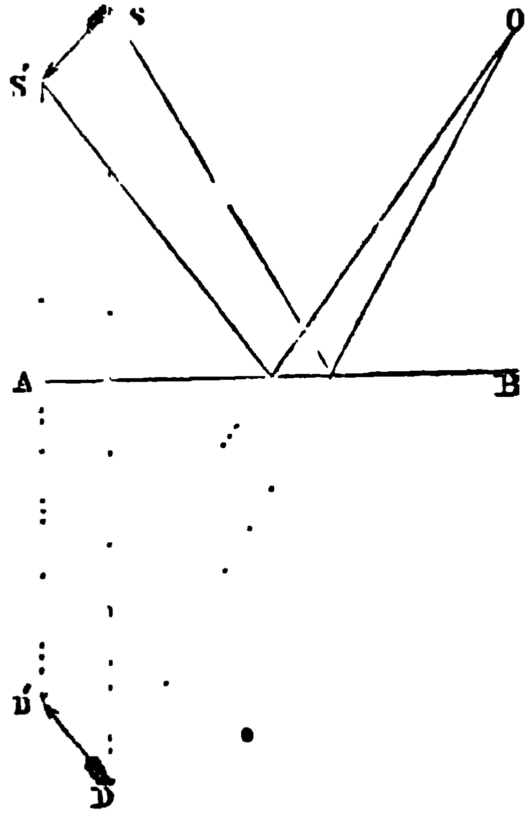

Fig. 3.

If the luminous object be of a certain extent, each of its radiant points will form its own separate image, in accordance with the laws we have just explained, and these images, taken together, will form that of the object. Let us suppose for instance that the object is an arrow SS': the butt S of the arrow will form its image at D, the point S' will form its own at D', and the intermediate points will present theirs along the line D D'. Thus the whole image will be comprised between the extreme reflected sets or pencils of rays DO and D'O its absolute size DD' will be equal to SS', that is to say, to that of the object itself, but it will appear inverted from right to left.

These observations are sufficient for the solution of all questions that can possibly arise with respect to the reflection of light, and the vision of objects by means of plane mirrors.

As for curved surfaces, of whatever form, to determine generally the apparent place, the form and size of the images they reflect, it is enough to consider the reflection of each luminous ray, as if taking place upon the plane tangent to the curved surface at the point of incidence. But for practical purposes, it is not necessary to apply this reasoning to all kinds of curves, for we never make use of any other than spherical reflectors, whether concave or convex, these being the only ones that can be shaped and polished with accuracy; and to obtain precise images even from these, it is necessary that the luminous rays should fall almost perpendicularly on their surfaces. We shall therefore confine ourselves to the examination of this single case.

Let us suppose then in space, a luminous point casting its rays on the several parts of a spherical surface, concave or convex, and confining our observations to one of them, let us investigate the direction in which it will be reflected.

Let MAM′ be the spherical mirror, S the luminous point, and SI the incident ray we are considering. From the point I to the centre of the sphere draw the radius IC, and lay down the angle CIR equal to CIS: IR will be the direction of the reflected ray.

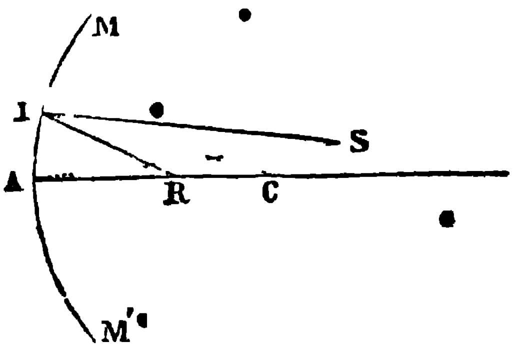

Fig. 4.

If we repeat the same construction for all the incident rays issuing from S, we shall find by our figure, as well as by calculation, that the reflected rays all pass very close to each other through a small space called the *focus*, R, forming here by their concentration an image of the point S: and this is also confirmed by experience.

By a similar construction and mode of reasoning, we should find that the image formed by a convex mirror is always imaginary, and takes place beyond the mirror, so that it can only be seen by the naked eye, but not received on a roughed glass or on a screen.

General Laws of the Refraction of Light.

We have just seen how that portion of the luminous ray conducts itself, which is reflected from the surface of bodies; we shall now follow that portion which traverses their substance.

The latter, when the incidence is oblique, does not continue in a straight line—it deviates from its course; this is the phenomenon called *the refraction of light.*

Whenever a luminous ray passes obliquely from one medium to another, it is refracted, and the extent of the deviation depends on the difference existing between the density and the constitutions of the two media. In all uncrystallized bodies, the refracted ray is simple, and coincides with the prolongation of the plane of incidence.* It approaches towards or recedes from the perpendicular to the common surface of the two media, according as it passes from the rarer into the denser, or *vice versâ*.

The next thing to be determined is the relation existing for every degree of incidence between the obliquity of the incident ray to the perpendicular, and that of the refracted ray; so that, one of these directions being given, the other may be calculated: and here we are aided by the two following laws discovered by Des Cartes.

1. *The incident ray and the refracted ray are always in one plane, perpendicular to the common surface of the two media.*

2. *The ratio of the sine of the angle of refraction to the sine of the angle of incidence, is always the same for the same media, whatever be the angle of incidence.* This is what is called *the ratio of refraction.*

The act of refraction is always accompanied by a remarkable phenomenon. The refracted ray is decomposed into rays of different colours, the refractibility of which increases from the red ray, where it is least, to the violet ray, where it attains its maximum. This is the phenomenon of *the dispersion of light.*

Besides the seven prismatic colours, experiments have also detected, in the refracted ray, rays of *caloric*, the intensity of which augments from the violet ray up to

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*To exemplify this, suppose the refracting medium to be water; if, then, we take a perfectly flat plate of metal, and plunge it into the water perpendicularly to its surface, in such a position that the incident ray shall pass along one of its surfaces on its way to the point of incidence, the refracted ray will, in like manner, pass along that part of the same surface which is immersed. Some crystallized bodies, as, for instance, Iceland spar, possess the property of *double refraction:* one part of the light incident upon them is refracted in the plane of incidence; the other, called the *extraordinary ray*, is thrown out of that plane, and exhibits peculiar properties, constituting what is called *polarized* light.—TRANS.

and beyond the red, and *chemical* rays, the intensity of which follows a diametrically opposite course; that is, it is at its minimum in the red ray, and its maximum lies beyond the violet.

Lenses.

When a ray of light is received on a glass prism, it is refracted and approaches the base of the prism, in conformity with the laws we have just expounded. Now we may conceive a system, a combination of prisms, shaped and arranged in such a manner that the rays refracted by them shall converge to the same point. We can very readily imagine how desirable it would be to be thus able to concentrate in one point, a great number of rays of light; but the difficulty of constructing such an apparatus with sufficient accuracy would have greatly hindered the progress of science, if by rare good fortune it had not happened to be ready constructed in spherical lenses, which are nothing else than a combination of prisms, and which may be executed with accuracy and facility.

Lenses are of various kinds.

1. The doubly-convex lens. The resemblance of this form to a lentil, suggested its name, which has since been extended to all the other spherical glasses.
2. Plano-convex.
3. Concavo-convex, or meniscus.
4. Plano-concave.
5. Doubly-concave.

These forms may all be divided into classes, according as the bases or the points of the constituent prisms are turned towards the axis of the lens; and as refraction always takes place towards the base of the prism, the former will cause the rays of light which fall in a parallel direction on their surface, to converge—the latter, to diverge; hence they are called, respectively, converging and diverging lenses.

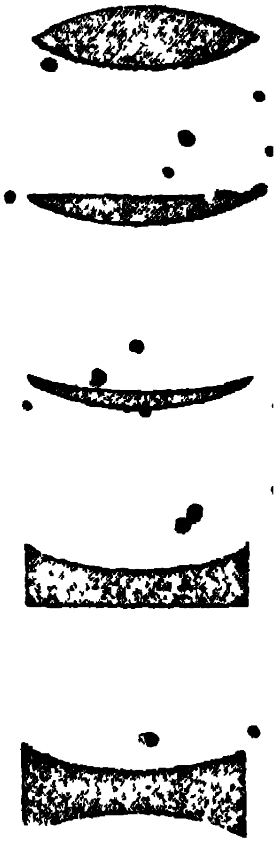

Fig. 5.

We know how these different classes of

lenses are made to assist vision, in correcting the too weak convergence of the rays on the eyes of long-sighted persons, and its too rapid convergence in the short-sighted. But it does not concern our present purpose to dwell on this.

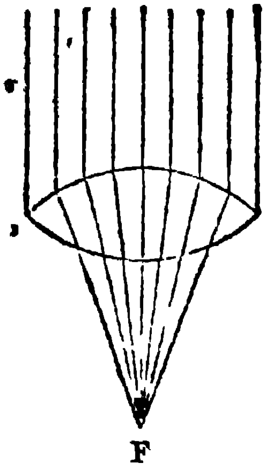

Fig. 6.

Let us cause a pencil of parallel rays to fall on a convex lens, and examine the result more closely. Amongst the incident rays, there is one that coincides with the axis of the lens, and traverses it without being refracted; but this is not the case with the others, which undergo a refraction, the greater in proportion as they are further removed from the axis, so that they all converge towards the same point F. This point is called the *focus* of the lens. We perceive that the greater the convexity of the lens, the greater will be the refraction, and consequently the shorter the distance of the focus.

Reciprocally, if having arrived at the focus F, the rays of light now retrace their course, they will be refracted by the lens, and will escape from it all parallel; whence follows this remarkable inference: that if from the focus of a lens, rays of light be directed upon every part of its surface, they will form on issuing from it a parallel pencil.

This property of lenses has given birth to an extremely useful contrivance: the lighthouse lamp is nothing more than a combination of four lenses, in the common focus of which a lamp is placed, the rays escaping from which arrange themselves in parallel pencils on issuing from the lenses, and no longer weakened by dispersion, lose nothing of their intensity, except what is absorbed by the imperfect transparency of the atmosphere, so that they can illuminate the most distant portions of the horizon. But as the diameter of these luminous pencils is necessarily circumscribed, and as in spite of the eccentricity of the lamp, its light can irradiate only a part of the horizon at a time, the expedient has been devised, in order to direct the light upon every point of the horizon successively, of making the lighthouse revolve on its centre in a given time, which, varying for each lighthouse, serves to distinguish them all from each other. Thus this useful apparatus not only warns the mariner of his approach to the coast, but moreover indicates to him his position by its mode of rotation.

Another property of lenses is that of enlarging the images of objects. Let us remember that the apparent dimensions of a body depend on the angle under which it is seen, and that this angle varies inversely as the distance of the object from the eye of the observer. Whence it follows, that to see an object under large dimensions, we should only have to place it close to the eye, if vision could take place thus with distinctness; but the great divergence of the rays in this case renders the image confused. To avoid this, let us look at the object through a converging lens. The parallelism of the rays will allow of the eye approaching as much as we please, and the image of the object will appear under an angle, equal to that under which the object itself would be seen by the naked eye, if direct vision could possibly take place at so short a distance. Hence we perceive that the magnifying power of a lens is the greater, the less its focal distance.

In the experiment we have just mentioned, the idea we form of the real size of an object, is determined by the angle under which it is seen, without our being able to modify it by any previous experience of the relation between distances and visual angles. This is not the case in the ordinary process of vision. Two things enter into the judgment which we form of the size of objects—the angle under which we see them, and the distance at which we suppose them to be. Thus we judge very well of the height of two men placed at unequal distances from us, and consequently seen under different angles, because we make allowance for the distance. So true is this, that the invariable habit of allowing rigidly for distance, leads us into error as to the real dimensions of the body when we are mistaken as to the distance. Thus objects seen through an opera-glass do not appear magnified, because we think them nearer, and yet such glasses magnify two or three times, as we may convince ourselves by looking with one eye through the opera-glass, with the other naked. Here is another experiment: place an object on an horizontal plane, and place your eye in the continuation of the same plane; then look at the object, while you push your lower eyelid slightly with your finger, so as to see two images; that which is nearer to you will appear smaller than the other, and will appear to diminish in proportion as it approaches you more. The proof that this opinion as to the respective size of the images depends on the supposed distance is, that they will appear to you equal when you shall have placed the object on a vertical plane, so as to obtain the two images one above the other.

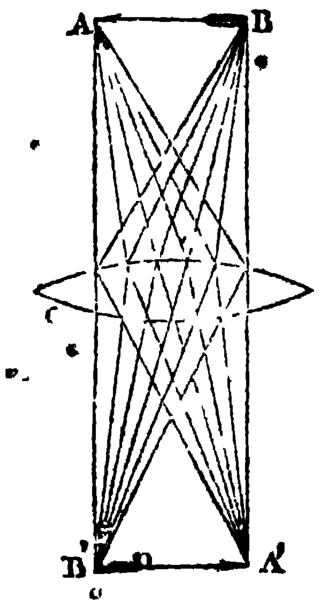

Fig. 7.

To return to our lenses. We have seen under what laws a pencil of parallel rays is refracted; let us see how rays issuing from the different points of an object are refracted. Let AB be an illuminated object. It is evident that from each point of this object will issue a pencil of rays, whose point of convergence will be found somewhere in the prolongation of that ray of the pencil, which, having encountered two parallel faces, has not undergone any refraction.

Thus the point A will be imaged at A′; the point B at B′, and the intermediate points along the line connecting A′ and B′; and if these rays be received on a sheet of paper or of ground glass, we shall see a reversed image of the object AB.

We have already remarked that a refracted ray of solar light decomposes into rays of different colours. This decomposition colours the image and renders it confused. So great is the inconvenience resulting thence, that Newton, knowing no remedy for it, regarded it as decisive of the unfitness of refracting telescopes for astronomical purposes. But since his time, means have happily been found for remedying this defect. This consists in combining together lenses formed of substances which, though they equally refract light, yet disperse it unequally. Crown glass and flint glass fulfil these conditions; and it is by combining these two kinds of glass in the proper proportions, that we have succeeded in obtaining the achromatic object-glasses employed in the present day.

Refracting and Reflecting Telescopes.

Astronomical refracting telescopes may be regarded as consisting essentially of two glasses: the one named the object-glass, receives the rays proceeding from the object and forms an image of it in its focus; the other, the eye-glass, serves for looking at this image. The enlargement produced by this kind of telescope, proceeds from two causes: the image formed in the focus is already enlarged when seen by the naked eye, because it is at a distance of but seven or eight inches from it, a distance much less than that which separates the lens from the focus, so that it is thus seen under an enlarged angle; but its enlargement is particularly due to the eye-glass, which is a lens of very short focal distance. Astronomical refracting telescopes are very powerful: some of them magnify as much as a million of times.

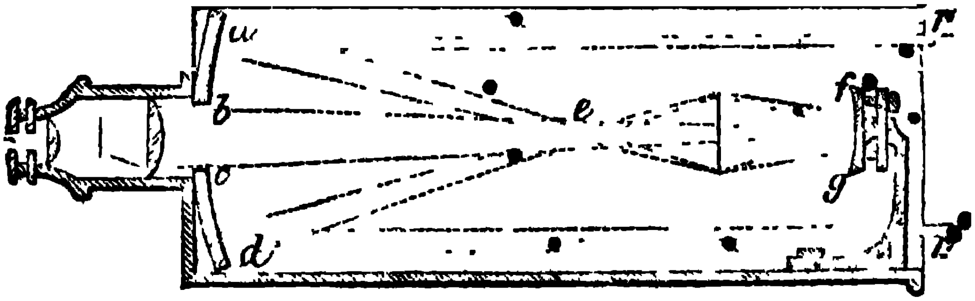

Fig. 8.

Reflecting telescopes consist of a polished metallic reflector *abcd*, in the focus of which, *e*, the image is formed by reflection; but as this image cannot be seen through the reflector, a small mirror *fg* is employed to project it laterally, or else behind the reflector, through a small opening *bc*, made in it for the purpose. The original rays *ra*, *rd* are supposed to strike parallel upon the reflector. This double reflection is attended with the inconvenience of considerably diminishing the light; for it is well known that the most polished mirror hardly reflects more than half the light incident upon it. Thus with equal dimensions, a reflecting telescope has only a fourth part of the power of a refracting telescope, for refraction does not sensibly diminish the light.

To measure the height of the stars, and for a multitude of other operations, refracting telescopes have in their field of view metallic threads variously arranged, and of extreme delicacy, since they are considerably finer than spider's threads. The means by which they are procured is ingenious: these threads, which are of platina, are first drawn out as fine as they can be made with the wire-drawing apparatus. They are then put into cylinders, into which melted silver is poured, and thus they form the axis of silver cylinders, which are themselves subjected to the wire-drawing process. The platina being thus further reduced in dimensions, to free it from the silver, the whole is plunged in nitric acid, which dissolves the silver without acting on the platina.

Structure of the Eye.

We shall conclude this first lecture with an account of the organ of vision, the most wonderful of all optical instruments. In man this organ is formed of different transparent media, the curvatures and refractive forces of which are so combined as to correct the aberrations of sphericity and refraction. The images are formed on a nervous membrane lining the bottom of the eye, which transmits to the brain the impressions it receives.

This organ is composed of three transparent media, differing in form and in refractive power. The first is a convexo-concave meniscus, filled with a transparent liquid, similar in appearance to water, and hence called *the aqueous humour*. Next comes a solid transparent body in the form of a doubly-convex lens, and called the *crystalline lens*, *p* H *p*. It is less convex anteriorly than posteriorly, and its flatness increases with age. Finally, the whole of the posterior chamber is occupied with a viscid fluid, like melted glass, and therefore called the *vitreous* humour. The membranes enveloping this whole apparatus, may be regarded as prolongations of the integuments of the optic nerve. The exterior integument of the nerve gives origin to the outer coat of the eye, which is tough, opaque, but yet flexible, somewhat like horn, and is called, for this reason, the *sclerotic* or the *opaque cornea*, ABCD. But arriving in front of the eye, this membrane becomes thinner and transparent, like a watch-glass, in order to give passage to the light: it then takes the name of the *transparent cornea*, AED. Here it is covered by the skin, which in this place is of extreme thinness. The second envelope of the optic nerve expands beneath the former, and forms a coat called the *choroïd*, which is covered with a black pigment; for, just as we blacken the interior of the tubes of our telescopes, it is necessary that the interior of the eye too should be blackened, to prevent the confusion which would otherwise have resulted from the multiplied reflection of the rays. Lastly, the interior medullary portion of the optic nerve, expanding in its turn like the former, forms a nervous membrane of a greyish white colour, resting on the choroid, and denominated the *retina*. It is presumed to be the seat of vision.

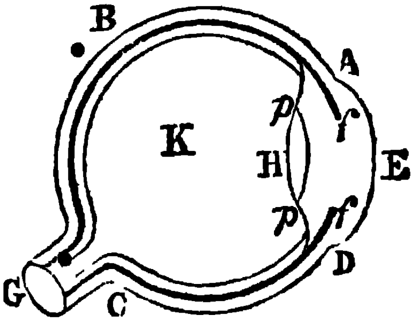

Fig. 9.

It is now easy to understand in what way vision is effected. The rays issuing from external objects, fall on the cornea, traverse the aqueous humour, the crystalline, and the vitreous humour, and concentrate themselves on the retina in the focus of the instrument, where they form a small reversed image. This can be seen in the eyes of men or animals extracted shortly after death. In we carefully pare away the upper part of the sclerotic, and place a strongly illuminated object in front of the eye at a convenient distance, we shall see, on looking backwards, a very exact image of the object formed at the bottom of the eye, varying in size inversely with the distance.

In optical instruments exact and distinct images cannot be procured of objects at unequal distances, unless by means of proportionally varying the focal lengths of the instrument. By what mechanism is this condition fulfilled in the eye, in which vision is effected with equal distinctness at very various distances? for, that something takes place analogous to the variation of the focal lengths of the instrument, is proved by the fact, that the eye requires a certain time, and even the exertion of a certain effort, thus to vary its range: of this we may satisfy ourselves by placing a small object, as for instance a hair, at a short distance from the eye, so that it may be projected on another more distant object: it will be impossible for us to see both objects distinctly at once, but the eye will be forced to pass alternately from the one to the other. Anatomy, however, has vainly endeavoured to discover by what mechanism the organ is enabled thus to vary its effects. It was at first supposed that the anterior part of the cornea was capable of voluntarily assuming a more or less convex form, or else that the retina had the power of advancing or retiring a little to meet the shifting positions of the focus; but accurate experiments have proved the fallacy of these two hypotheses. There remains then the crystalline lens to effect the phenomenon in question; and it appears probable, although the opinion does not seem countenanced by anatomy, that it is to the crystalline lens the eye owes its power of seeing distinctly at various distances; for with the loss of the crystalline lens the eye loses this faculty. Thus persons who have been operated upon for cataract, that is, who have had the crystalline lens destroyed when it had lost its transparency, do not see well but at a certain distance, and that generally a long one.

But how is it this act of vision gives rise to sensation? We cannot tell; all we know is, that the impression produced on the retina is transmitted to the brain by the optic nerve. Reasoning from this fact, Mariotte supposed that the more the image approached the point from whence the nerve begins to expand into the retina, the more acute would be the sensation, and that it would reach its utmost intensity when it was formed exactly over that point. Experiment presented him with a diametrically opposite result; for he recognised, by means of a very simple process, that this point of the retina is insensible, and that an object becomes invisible as soon as it is so placed that its image may fall on this spot.

The axis of the eye, that is, the direction in which we habitually look, is not that in which we see objects best. This is the reason why astronomers say, that to see a star, one should not look at it; that is to say, that one sees it better by looking at the part of the heavens near that which it occupies.

The sensation produced on the retina by the rays of light is of some duration; this is the reason why a live coal, swung rapidly round, appears a luminous hoop: and if such a coal were made to turn behind an opaque screen with a hole in it, so that the coal could only be seen as it passed the hole, it would appear there continually, if the motion were sufficiently rapid that it should present itself ten times in a second.

When we look for a long while on one colour, it produces a morbid sensation in the fibres of the retina, unfitting it for some time to perceive that colour, and making its complementary colour predominate. Thus, after having looked for some time on red or green, we see green or red spots on the objects we turn our eyes upon; because these two colours are complementary the one of the other; that is to say, mixed together, they produce white.

It is probable that the fibres which perceive one colour, are not those that perceive another. Such at least appears the inference from a well-authenticated fact; namely, that there are persons who do not perceive all colours. Colardeau was in this predicament. He sometimes employed himself with painting, and one day made the ground of a picture scarlet, thinking to make it blackish; when this was pointed out to him, he could not perceive any difference between these two colours. There exists at this day in England a distinguished man of science, who perceived, on examining certain plants, that he had not the consciousness of every colour; and the annals of the Académie make mention of an entire family, who confounded green with red, so as not to be able to distinguish cherries from their leaves otherwise than by their form.

LECTURE II.

HISTORY OF ASTRONOMY—DEFINITION—SIGNS OF THE ZODIAC.

History of Astronomy.

A DENSE cloud rests upon the cradle of all the sciences, but of none perhaps is the history involved in so profound obscurity as that of Astronomy. Coëval with the world, connected with the first wants of man, it must from the first have excited his curiosity and attracted his observation. But those first elements of the science, collected in various places, and at remote epochs, remained lost to the science, as they are for its history.

We do not propose, therefore, to take Astronomy from its cradle, and follow its course down to our day, without ever losing sight of it for a moment amidst the obscurity that rests upon its path, but only to point to it at intervals on its way, as it gleams out from the darkness.

The Chaldeans were probably the first who turned their attention to Astronomy. This pastoral people inhabited the delightful regions of Asia, the most beautiful portion of the globe. The habit of passing the night in the open air, the purity of the sky, the immensity of their horizon—all these must early have solicited their attention to the movements of the heavenly bodies, and to the study of their imposing phenomena.

From Chaldea it was not long before Astronomy spread into Egypt, that cradle of the arts and sciences: there it made great progress. The priests took it up, mingled it with religion, and employed it as an instrument of their sway over a credulous people, whom they laboured to retain in ignorance and superstition.

The Phœnicians were the first who applied astronomical observations to navigation. They had remarked that, amidst the general movement of the sphere, one of the stars of the Lesser Bear appeared always to remain in the same position. It was by this star they steered their course; and such was their superiority, that in the time of Nechos, at a period when other people hardly dared to quit the coasts, they had set off from the Red Sea, circumnavigated Africa, and returned the third year to the mouths of the Nile.

Nearly at the same epoch Astronomy was introduced from Phœnicia into Greece by Thales. He taught the Greeks, who only knew how to observe the Great Bear, how much more sure a guide the polar star was to the mariner. He taught them the movements of the sun and moon, whence he derived the explanation of the length of days, and the determination of the solar year. He was acquainted with the cause of eclipses, and even it appears with the means of predicting them; for he acquired great celebrity by foretelling one that occurred on a day of battle between the Medes and the Lydians.

Anaximander, one of his disciples, invented the terrestrial globe; he also constructed at Sparta the gnomon that enabled him to observe the equinoxes and the solstices, and determined the obliquity of the ecliptic with tolerable precision. The Greeks were not slow in applying these novel ideas to the benefit of their navigation, but they were not grateful to the sage to whom they were indebted for them. They proscribed and would have put him to death, if Pericles had not succeeded in rescuing him from the superstitious populace. His crime was, his having taught that the universe is governed by immutable laws.

Pythagoras, who likewise lived about five centuries before our era, greatly enlarged the science. He enriched it with almost all the grand views on which it reposes at the present day. It was he who first discovered the system of the universe to which Copernicus has bequeathed his name. It was he who first conceived the bold idea that the planets are inhabited globes like that on which we move, and that the stars that people the immensity of space are so many suns destined to afford light and heat to the planetary systems gravitating towards them. He saw too in the comets, not fugitive meteors formed in the atmosphere, but permanent stars revolving round the sun, according to laws peculiar to themselves.

The first who taught the classification of climates according to the days and nights was Pytheas, who, about 400 B.C., either originated or witnessed the origin amongst the Greeks of a decided taste for Astronomy. No longer able to satisfy its cravings at Athens, they ascended to the sources of the science—they went to study it in Egypt; and Eudoxus, who died B.C. 352, brought back thence on his return new details, which he announced in several works. It was he who explained to the Greeks assembled at the Olympic games, and caused them to adopt, the famous cycle of nineteen years devised by Meton, B.C. 432, to reconcile the motions of the sun and moon. The year of this cycle is still indicated in our calendars under the name of the *Golden Number*.

All the sciences are linked together, and mutually aid each other. Astronomy applied itself to the service of natural philosophy and geography, and lent them its light. Aristotle determined the figure and size of the earth by astronomical observations. He derived proof of its sphericity from the appearance of the circular shadow it projects on the disk of the moon in eclipses, and from the unequal elevation of the solar meridian in different latitudes. He died B.C. 322.

Thus it was that the domain of Astronomy became enlarged under the hands of these celebrated philosophers. But amongst all the schools of antiquity in which this science was taught, that of Alexandria stood proudly and deservedly conspicuous. It collected skilfully a number of observations made with trigonometrical instruments, carefully described the constellations, determined with precision the positions of the stars and the courses of the planets, and began to account for the inequalities in the motions of the sun and moon. Hipparchus (150 B.C), of this school, determined the length of the tropical year with a precision not previously arrived at; he came within four minutes and a half of the real time.

Ptolemy, who is regarded as the first of astronomers, lived in the second century after Christ. He has handed down to us, in his great *Syntaxis*, the principal observations and discoveries of the ancients. In this work he has given the theory, and tables of the motions of the sun, the moon, the planets, and the fixed stars. He had adopted the theory which supposes the earth placed in the centre of the universe, which theory has received his name. The inaccuracies it involves did not hinder the great man's calculating the eclipses which should occur in the six ensuing centuries.

The *Syntaxis* was translated about the year 826 by the Arabs, and called *Almageste*. Four centuries later the translation was rendered into Latin by order of Frederick the Second. Alphonso of Castile then assembled the principal known philosophers, and caused them to draw up new tables, which were called *Alphonsines*.

This patronage was not without its effect on the enlightened men of Europe. Astronomy led to favour and to fame; and they cultivated it. Treatises were multiplied, and with them instruments to facilitate observations. But the most memorable event of the period was the reproduction of the old system of the universe discovered by Pythagoras. It was Copernicus, born at Thorn in 1472, who revived it. He found that the system of Ptolemy, which supposed the earth fixed, and the sun, the moon, and the planets, turning round this body in concentric circles, was not in accordance with the phenomena. He observed that the difficulties with which it was embarrassed, disappeared on admitting that the sun is a centre, round which the earth performs, like the other planets, its annual revolution. This theory is based on arguments so incontestable that it is the only one at present taught in Europe. Unfortunately Copernicus had not the satisfaction of witnessing the triumph of the doctrine he so ably defended Persecuted by fanatics, a victim to the intrigues of the learned, it was not till long after he had completed it, that he published the book in which he had recorded the result of his observations. He saw the first copy of it, but in a few days afterwards he was no more.

The only opposition of any moment offered to the system of Copernicus was made by Tycho Brahé, a celebrated Danish astronomer, who opposed to it a theory of his own. His system differs little from that of Ptolemy ; it bears his name, however. He supposes that the earth is in the centre of the universe, and that the sun accomplishes its revolution round it in twenty-four hours. The planets do the same by him, but in periodic times : Mercury first, as being at a less distance ; then Venus, Mars, Jupiter, and Saturn, which describe the same orbit. Some of his disciples, however, supposed that the earth was actuated by a diurnal motion round its own axis, and that the sun and all the planets made their revolutions round the earth in a year. We shall demonstrate the viciousness of this system when we come to treat of that of Copernicus.

One of Tycho Brahé's disciples, Kepler, gave a great impulse to this science. Hipparchus, Ptolemy, Copernicus himself, owed a great part of their information to the Egyptians, the Chaldeans, and the Indians ; they followed a beaten track ; but Kepler owed to his genius alone the discoveries that have rendered his name so celebrated : antiquity had not bequeathed to him any indications to direct him on his course.

Galileo lived at the same period. Whilst the one traced the orbits of the planets and discovered the laws of their movements, the other subjected to his researches the laws of motion in general, which had been neglected for two thousand years. It was by availing themselves of the labours of these two philosophers, that Newton and Huygens were enabled subsequently to determine all the planetary motions; Galileo had proved beyond dispute that the earth possessed a diurnal and annual motion; but his doctrine was contrary to the received opinions of the day. The cardinals cited him to appear, and, without regard to his age, his virtues, and his knowledge, they condemned him to perpetual imprisonment.

Since the days of Newton, who brought it to its present advanced condition, Astronomy has been continually cultivated by men who have become distinguished for their great acquirements and their admirable discoveries; but we must not dwell longer on the history of the science.

Preliminary ideas—Definitions.

Astronomy treats of the motions, the distances, the size, the physicial constitution, the eclipses, and all other phenomena of the heavenly bodies.

Under the general name of *stars* are vulgarly comprehended all the bodies that fill the celestial space; but Astronomy ranges them into several classes.

In the language of Astronomy, those are called *fixed stars* which in the revolution of the sphere seem always to occupy the same relative position, and to preserve the same distances the one from the other. For the greater facility in recognising and designating them, they are divided into groups, called *constellations.* Each of these has its proper name, derived from that of a man or an animal, sometimes suggested by its form, but almost always capriciously chosen. The utility of these names has continued them amongst us. To distinguish the several stars of a constellation from each other, they are classed according to their brilliancy or their apparent magnitude, and each class has a particular denomination. Thus the most considerable are arranged into classes or *magnitudes;* and the others are marked according to the method of Jean Bayer, in the celestial maps published by him: this consists in designating each of them in the order of their magnitude by the letters of the Greek alphabet, beginning with α for the first, β for the second, and so on. If the letters of the Greek alphabet are not sufficient, recourse is had to Roman letters, and even to the ordinal numbers, 1, 2, 3, &c. This nomenclature has been followed by all modern astronomers.

Observations having shown that certain stars, besides the daily revolution which they have in common with the other heavenly bodies, have besides a motion peculiar to themselves, which alters their relative distances from the other bodies around them, these stars have received the name of *planets,* from a Greek word which signifies *wandering.*

Herschel defines the planets to be celestial bodies of considerable magnitude, and with slightly eccentric orbits, moving in planes that deviate but a few degrees from that of the earth, in a direct course, and in orbits very remote from each other, with vast atmospheres, which yet bear scarcely any sensible proportion to their diameters. They have satellites or rings.

The planets are distinguished into *primary* and *secondary.* The primary planets are those which turn round the sun as a centre; and the secondary, more frequently called satellites or moons, are those that revolve round a primary planet as a centre, and are carried with it in its revolution round the sun.

The primary planets again are divided into *superior* and *inferior.* The superior are those more remote from the sun than the earth, as Mars, Jupiter, Saturn, Uranus, and Neptune; the inferior are those that are nearer the sun than we, as Mercury and Venus.

As for the small planets discovered at the beginning and middle of this century,—sometimes called *telescopic* planets, because seen only with a powerful telescope—Herschel has proposed to give them the name of *Asteroïds,* under which name he includes those celestial bodies which move in orbits of any eccentricity round the sun, whatever angle their orbits make with the ecliptic, whether the motion of these bodies be direct or retrograde, whether they have or have not atmospheres.

The following symbols are used to designate the planets in tables and on globes:—Mercury ☿, Venus ♀, the Earth ⊕, Mars ♂, Vesta ⚶, Juno ⚵, Ceres ⚳, Pallas ⚴, Jupiter ♃, Saturn ♄, Uranus ♅, Neptune ♆.

The *orbit* of a star is the course it describes round that which serves it as a centre. The orbits of the planets are ellipses of very slight eccentricity; those of the comets, on the contrary, are very eccentric; that is to say, they deviate greatly from the circular form, and are lengthened considerably.

An *ellipse* is a section of a right cone by a plane oblique to its base, but which does not meet it. To describe it, fix a circular thread by two points, and keeping it at full stretch with the point of a pencil, carry the pencil all round: the two fixed points are the *foci* of the ellipse, and its eccentricity is its distance from the centre to the foci.

The *ecliptic* is the orbit described apparently by the sun round the earth, and in reality by the earth round the sun.

The *sensible horizon* is a plane tangent to the globe at the point where the observer is stationed. It is the plane of the circle that bounds our views.

The *rational horizon* is a plane passing through the centre of the earth parallel to the sensible horizon.

The *colures* are old terms designating two great circles of the sphere, which pass, the *equinoctial colure* through the equinoctial points and the poles of the equator, the *solstitial colure* through the solstitial points and the poles of the ecliptic and the equator.

The *meridian* is a great circle of the sphere passing through the poles.

Altitude is an arc of a vertical circle, included between the object and the horizon.

Azimuth is the arc of the horizon included between the meridian and the vertical plane containing an object.

Terrestrial longitude is the angle formed by two meridians measured by the arc of the equator, or of its parallels intercepted between them. The *longitude of a star* is the arc of the ecliptic intercepted between the star and the first point of Aries.

Terrestrial latitude is the distance of a place from the equator reckoned on the meridian, and the *latitude of a star* is its distance from the ecliptic, measured on the great circle passing through the star and the pole of the ecliptic.

Two planets are in *conjunction* when they have the same longitude; they are in *opposition* when their longitudes differ by 180°.

Declination is the distance from the equator of the parallel described by a star; it is austral or boreal (southern or northern).

The *zenith* is the summit of the celestial dome above and around us; it is the point directly over our head, the upper pole of the horizon.

The *nadir* is the point diametrically opposite, or the lower pole of the horizon.

The *poles* are the extremities of the axis of a circle.

The *nodes* are the points where the orbit of a planet cuts the ecliptic. The node whence the planet rises towards the north above the plane of the ecliptic is the *ascending node*, that whence it descends towards the south is the *descending node*. The line joining the two is called the *line of the nodes*.

The *solstices* are the two extreme points of the sun's apparent course north and south of the equator.

The *tropics* are circles corresponding to the sun's position at the solstices; they are the limits of the torrid zone.

The *celestial sphere* is the great concavity apparently formed by the space surrounding our globe, in which we see the celestial bodies. It appears to revolve upon the two poles.

Apogee is that point in a planet's orbit in which it is farthest from the earth and its *perigee* is that in which it is nearest to it.

Apsides are those points in the orbit of a planet in which it is at its greatest or least distance from its primary. The first of these points, that is, the point of greatest distance, is called *aphelion,* the other *perihelion:* this, however, refers to the sun. In the case of the moon, whose primary is the earth, the apsides are termed *apogee* and *perigee.* The line joining them, and passing through the sun's centre, is called the *line of the apsides.*

Syzygy is the name given in common to the moon's opposition to, and her conjunction with, the sun.

The *equator* is a great circle, every point in which is equally distant from the poles.

Those places with respect to which the poles are situated in the horizon, are said to have a *right position of the sphere.* Those whose horizon coincides with the equator, have a *parallel position of the sphere.* For all intermediate places, the position is *oblique.*

A *parabola* is a section of a cone by a plane parallel to the side of the cone: it is therefore an open curve.

Parallax is the angle formed by the two lines, in the direction of which a star would be seen at the same instant from the centre of the earth, and from a point on its surface.

The *zodiac* is a zone about eighteen degrees wide, and is cut by the ecliptic into two equal portions. It is divided into twelve parts called *signs*, and each sign into thirty degrees. The signs of the zodiac have each a special name and symbol; they are:

♈ Aries.
♉ Taurus.
♊ Gemini.
♋ Cancer.
♌ Leo.
♍ Virgo.
♎ Libra.
♏ Scorpio.
♐ Sagittarius.
♑ Capricornus.
♒ Aquarius.
♓ Pisces.

They are situated in the foregoing order, reckoning from west to east, and this is called the order of the signs. As an assistance to the memory, the following Latin hexameters have been constructed:

Sunt Aries, Taurus, Gemini, Cancer, Leo, Virgo,
Libraque, Scorpius, Arcitenens, Caper, Amphora, Pisces.

The etymological explanation of these names has given rise to numerous discussions, which the Egyptian Institute has lately brought to a close, by showing that the names, now universally adopted wherever astronomy is cultivated, are derived from comparisons made by the Egyptians between celestial phenomena and terrestrial ones, for the most part purely of a local nature, and belonging exclusively to a part of their country. The following brief abstract of this curious investigation cannot fail to prove interesting to the reader, if he only remember that the respective signs, about to be detailed, are, at the times specified, in *opposition* to the sun;—that the earth, viewed from the sun, would be seen in those signs.

1. Capricornus (Caper) ♑.

The first month of summer: it extends from the 20th of June to about the 20th of July.

In Greek, Επιφι επηφι (Alberti, *Fabricii Menologium*).

Coptic, *Epep* (Lacroze, *Lexicon Egyptiano-Latinum*).

Arabic, *Hebbêbi*, *hebbêb*.

Latin. These different names may be thus interpreted: *Caper, dux gregis, qui cœpit, species apparens aquæ, evigilatio, motio huc et illuc, aurora.*

The Arabic verb *hebbêb* or *habêb* signifies *cœpit, evigilavit, experrectus fuit è somno, flavit ventus, vacillavit, huc et illuc motus fuit, insiliit in favillam.*

The following is the explanation of the Latin phrases equivalent to the Arabic and Coptic words.

Caper gives name to Capricorn, one of the twelve signs of the zodiac.

Dux gregis, qui cœpit. Capricorn opens and begins the year: he is the leader of the celestial animals, as on earth he is the leader of the flock.

Species apparens aquæ: commencement of the rising of the Nile, which usually does not make its appearance till ten days after the solstice.

Qui evigilavit, experrectus fuit è somno, points to the longest day: the sun, or the animal that represents it, is awake, and rouses the world at the hour in other seasons appropriated to sleep.

Qui vacillavit, qui huc et illuc motus fuit : the hesitating motion of the sun when arrived at the solstice.

Qui flavit ventus : the northern winds blow for fifteen days at this period. The almanac of the Egyptians announces their arrival.

Aurora: this proves that the Egyptian year commenced at the aurora of the goat, at the dawn of the first day of summer. Finally, Epiphi or Epephi, according to Herodotus, was probably one of the twelve astronomical gods of the Egyptians; for he says, book ii. chap. 38, that oxen were sacred to this god.

2. Aquarius ♒.

Aquarius was the second month of summer, and lasted from the 20th of July to the 20th of August.

Greek, Μεσορι, Μεσσορι, Μεσσωρη, Μεσωρῆ, *Menologium.*

Coptic, *Mésoré.*

Arabic, *Mesour, misr, vas aquæ paulatim lac suum reddens.*

The Arabic verb *meser* is translated *præbuit paulatim, emulsit quicquid esset in ubere.* The addition of a final *y* makes the impersonate word *mesouri*, signifying *aquarius.*

Paulatim lac suum reddens, etc., agrees perfectly with the figure of Aquarius in the zodiacs of Essori and Denderah, in which the vessel very slightly stopped lets the water it contains slowly escape.

Emulsit quicquid esset in ubere. It is during this month, or thereabouts, that the sources of the Nile give out their full complement of water. The Egyptians regarded this fluid as equally mild and nutritive as milk. The inundation augments during this month.

3. Pisces ♓.

The third month, from the 20th of August to the 20th of September.

Greek, Τωθ, θωυθ, θωθι, φθω.

Coptic, *Thoout.*

Arabic, *Thohout. Ambulatio piscis, incessus, reciprocatus ultro retroque in se rediens.*

The Arabic verb *tona* signifies *peragravit regionem, opplevit puteum.* From *hout*, a fish, comes the verb *hat, circumnatavit.*

Ambulatio, &c. exhibits the fishes moving backwards and forwards in the waters that cover the land.

Opplevit puteum, marks the inundation, covering all the low places, for it is spread over the whole of Egypt : the festival of Isis was fixed in this month, because it was also the season of the festival of the Nile, celebrated by opening the dykes. For this reason the month was sometimes called *fotouh, apertura per terræ superficiem fluentis aquæ*, opening of the dykes.

A passage in Sanchoniatho, preserved by Philo, says that *messori* gave birth to *bhoth*, and in reality, we see it is *messori*, or the rise of the Nile, that produces *touhout*, the expanse of water over the face of Egypt, in which the fish move about.

4. Aries ♈.

The first month of autumn, beginning the 20th of September, ending the 20th of October.

Greek, *Φαωρι, παιοφι, παω.*

Coptic, *Paopi.*

Arabic, *Fofo, foafi, hædus. velox, vox quâ greges increpantur.*

The Arabic verb signifies *increpuit gregem dicens fafa.*

The Hebrew verb *fafa* signifies *obtenebrescere.*

Vox quâ greges increpantur : as the waters retire, the ram again returns to the pasture, leading the flocks that have been held captive during the inundation.

Obtenebrescere : the day diminishes more and more, as is the case in the month beginning at the autumnal equinox.

5. Taurus ♉.

The second month of autumn, from the 20th of October to the 20th of November.

Greek, Αθωρ, αθορι (θωωρ, Eusebius).

Coptic, *Athor.*

Arabic, *Thaur, athour, taurus, tauri.*

The verb *athor, aravit, submovit terram.*

Tillage is not performed in Egypt till other countries have done sowing,—in the month of November.

6. Gemini ♊.

The third month of autumn, from the 20th of November to the 20th of December.

Greek, Χοιακ, χοιακ, κοιακ, κηκος.

Coptic, *Chorak.*

Arabic, *Chorik, amore flagrantes, amatores.*

In the Egyptian zodiacs, this sign is represented by a young man and a young girl: in this month seeds heat and germinate; the Greek appellation for this sign is but a vague one, *δίδυμοι.*

7. Cancer ♋.

The first month of winter, from the 20th of December to the 20th of January.

Greek, Τυβε.

Coptic, *Tobi.*

The verb *toby, amovit, avertit:* the verb *teb, reversus, conversus fuit, respuit.* These roots accord very well with the retrograde motion of the sun at the winter solstice.

8. Leo ♌.

The second month of winter, from the 20th of January to the 20th of February.

Greek, Μεχερ, Μεχειρ, Μεχος.

Coptic, *Chery* or *Mechery.*

The verb *cher, acquisivit, collegit; mecher, pars segetis,* or *mercher, protulit frondes, ramos; amcher, plantas suas extulit terrâ; inflatus turgidus, fuit.*

In Egypt the earth assumes its most beautiful aspect in the month of February; a part of the harvest is already begun: the king of animals was chosen to typify the strength and the magnificence of nature at this period.

9. Virgo ♍.

The third month of winter, from the 20th of February to the 20th of March.

Greek, Φαμενωθ.

Coptic, *Phamenoth.*

Arabic, *Famenoth. Mulier fœcunda et pulchra, quæ vendit spicam, frumentum, et quod portatur inter duos digitos.*

This word is compounded of *famij*, one who sells ears of corn, and seeds of all kinds, the ear or stalk of which can be carried between two fingers, and *cnoth*, a beautiful fruitful woman. In the Egyptian zodiacs, *Famenoth*, or the fruitful woman, holds an ear of corn in her hand: what led the Greeks into the error of calling this sign παρθενος, is that the Egyptian word signifies "endowed with beauty," but it also involves the idea of fruitfulness.

10. Libra ♎.

The first month of spring, from the 20th of March to the 20th of April.

Greek, Φαρμουθι.

Coptic and Arabic, *Faramour, mensura, regula confecta temporis.*

This month answers to the vernal equinox and the equality of the days and nights.

11. Scorpio ♏.

The second month of spring, from the 20th of April to the 20th of May.

Greek, Παχων.

Coptic, *Pachons.*

Arabic, *Bachony, prostravit humi venenum, aculeus scorpionis.* This word is compounded of *bach, prostravit, humi stravit,* which in all the Oriental languages signifies *putruit, læsit, pravus fuit,* or *putredo, malum, morbus,* and *honniy, venenum, aculeus scorpionis, terror.* It is characteristic of the second month from the vernal equinox, the heat of which stimulates venomous reptiles and excites disease and pestilence. The root *hama* also signifies *ferbuit dies;* the days become burning.

12. Sagittarius ♐.

The third month of spring, from the 20th of May to the 20th of June.

Greek, *Παυνι, παωνι.*

Coptic, *Paons.*

Arabic, *Fayne* or *fenni, extremitas sæculi temporis, Faijnan, fenan, nomen equi, onager varii cursus.*

The root *fanu* signifies *propulit, impulit; faijni* signifies *propulsator, impulsator.*

Extremitas: last month of the Egyptian year.

Nomen equi: onager: name of a quadruped. *Propulsator* indicates its action. In the Egyptian zodiac the animal is figured with the body of a quadruped and with a double head; one of a lion, the other of an armed man about to discharge an arrow: it seems to drive forward the animals that precede it, and to check those that follow; everything indicates that it will soon reach the goal towards which it is tending, and that its course is on the point of terminating.

LECTURE III.

ASPECT OF THE HEAVENS—APPARENT MOTION OF THE HEAVENLY BODIES—ASTRONOMICAL INSTRUMENTS.

Aspect of the Heavens—Apparent Motions of the Heavenly Bodies.

When we cast our eyes on the heavens, we behold a vast hemisphere expanding over our heads, whose centre we seem to occupy, and which appears to join the horizon at its base. By day this immense vault is lighted by a brilliant disk, which, issuing from the regions of the east, traverses it majestically, descends, and disappears again in the west. The feeble light it leaves behind is soon extinguished, and then appear from all sides in the immensity of space a multitude of brilliant points, of various dimensions, whose numbers augment as the darkness increases. The motions of these bodies add still more to the beauty of the spectacle. While some of them, moving in the same direction as the sun, proceed like him towards the west, and there sink beneath the horizon; others again make their appearance in the east, traverse the vault of the heavens, and disappear in their turn in the quarter where the sun passed from our view. All do not, however, thus sink below the horizon; some there are that for us never reach this circle, and whose course may be observed all the night through; one of them even appears constantly immoveable. Again, whilst some describe a vast arc in the heavens, others traverse a small arc above the horizon, and some even do but rise and disappear. Such are the phenomena of the rising and the setting of the stars. It is this general movement which the starry sphere accomplishes in a day and a night, that has received the name of the diurnal motion of the sphere.

In this revolution of the celestial sphere, the stars, as they undergo the motion we have just described, appear at the first view to retain the same relative distances. But more accurate observations soon show us, that, whereas the greater number of the heavenly bodies do indeed always preserve their relative positions, some of them possess a peculiar motion of their own, which carries them successively from one constellation to another. This is called the proper motion of the planets.

The sun, like the planets, seems to have a motion of its own, for we see it rise and set successively in different points of the horizon. At the end of June it rises near the north, remains a long while above the horizon, and approaches nearer the zenith; whereas, at the end of December, it rises nearer the south, keeps at a greater distance from the zenith, and describes but a small circle above the horizon. To this motion of the sun we owe the variety of the seasons and the inequality of the days.

The moon's motion, and the aspect she presents at different periods of her course, are still more remarkable. First, she begins to show herself on the western side of the heavens at a little distance from the sun, under the form of a crescent, which enlarges as the moon's distance from the sun increases, until at last it rises in the east when the sun sets in the west; her face is then exactly circular. She now bends gradually more towards the east, rises further and further so every night, till at last she is as near the sun in the east as she had been in the west. She then shows herself in the morning a little before him, as in the first part of her course she had appeared a little after him. These different phases are run through in the space of a month; after which they are repeated in the same order.

Sometimes, finally, we observe in the heavens luminous bodies quite different from those of which we have yet spoken, and which, from the various changes they undergo, have always been objects of popular wonder and curiosity. At first very small, and of little brilliancy, they soon acquire considerable dimensions, and exhibit luminous trains of very variable extent and splendour; these are comets. Possessed of motions of their own, whose direction is capable of change, the nearer they approach the sun, the more do their tails become developed in extent and brilliancy: at last, their lustre and their magnitude diminish with more or less rapidity, and they disappear wholly from our eyes.

On contemplating this revolution of the sphere, two questions present themselves to our minds. Does each star always employ the same time to complete its revolution? and is its motion uniform, that is to say, does it describe equal spaces in equal times?

To solve the first of these questions, no more is necessary than to direct towards any one star a telescope immoveably fixed in a suitable position. On counting the time elapsing till the same star re-appears in the field of the telescope, we soon find that the duration of the revolution is absolutely the same, wherever it takes place, and whatever be the star. The space of time elapsing between two consecutive returns of a star to the same meridian, constitutes a *sidereal day.*

The second question may be answered by means of an apparatus called a *parallactic instrument,* or *Equatorial.* It consists of a graduated circle immoveably attached to an axis passing through its centre, and perpendicular to its plane: this axis is also the diameter of a moveable circle, which is therefore constantly perpendicular to the first: this second circle, which is furnished with a telescope capable of assuming any inclination to the central axis, as it turns upon this axis, gives motion to a needle, that marks off on the first circle the horizontal axis traversed by the second. If the telescope be now directed towards a star constantly visible, it will be necessary, if we would not lose sight of it in the circle it describes, to put the axis of the instrument in the same direction as that of the heavens, and give the moveable plane a motion corresponding to that executed by the star: then if we note very exactly the intervals of time that elapse whilst the moveable plane traverses equal arcs on the fixed plane, we shall find that these intervals are all equal. To estimate, therefore, how much a star has changed place, it is indifferent whether we take for our measure the arc it has traversed, or the time it has spent in traversing it, when we have once established a known relation between these two data. Thus the sphere completing its revolution in twenty-four hours, and all the diurnal circles being divided into three hundred and sixty degrees, the stars

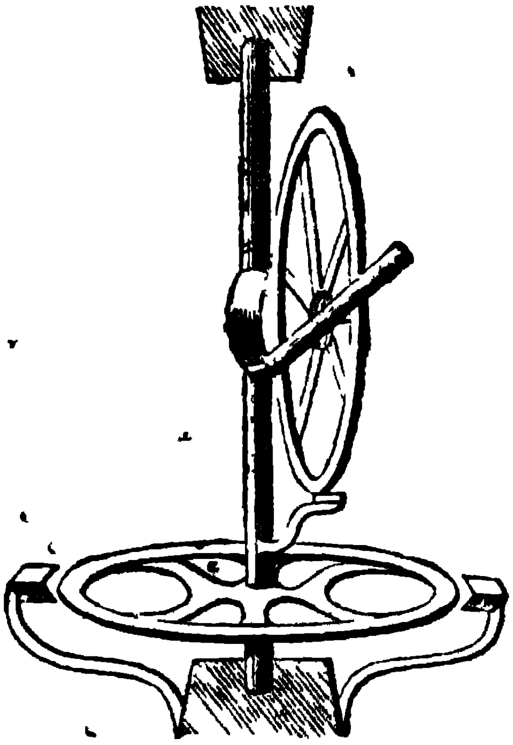

Fig. 10.

describe arcs of fifteen degrees hourly. We must remark, however, that these circles not being equal, their divisions do not coincide, and that in order to compare the results, we must determine their relative value.

It is a very common error to suppose that the stars are visible by day from the bottom of a well. They can only be seen by day with the help of telescopes, or by mounting in a balloon, or from the summits of lofty mountains. The reason why they are invisible by day to the naked eye is, that the sun's rays, reflected by the atmosphere, form a luminous curtain which prevents our seeing them, their light being incomparably too weak. In point of fact, it is enough that a light be sixty times weaker than another, to make it imperceptible to our eyes in presence of that other. This fact may be illustrated by a very simple experiment :—Place between two lighted candles an object that will thus project two shadows ; then remove one of the candles to such a distance, that the light it casts on the body be but a sixtieth of what it was before, a thing which may be easily effected, since we know that the intensity of light varies inversely as the square of the distance. The shadow projected by the light made thus remote will no longer be visible : if motion however takes place, it will become perceptible. This is the principal reason why stars are visible by daylight through optical instruments ; for since these instruments magnify, they prodigiously enlarge the distances traversed, and proportionately accelerate the motion.

Besides the peculiar motions which enable us at first to distinguish the planets and comets from the fixed stars, another difference soon arrests our attention, namely, the scintillation or twinkling exclusively observable in the fixed stars : this is a change in the intensity of their light often accompanied by a change of colour. To understand this phenomenon, we must have recourse to a remarkable discovery recently made in the properties of light. If we cause two rays of light having a common origin to meet in one point, they will not always combine to produce a greater volume of light ; on the contrary, it may happen, if we make them traverse different distances, or pass through media of different densities, that under the proposed conditions, these two rays, instead of mutually aiding, will mutually destroy each other; so that, however paradoxical it may seem, we shall have produced darkness by adding light to light. This is the phenomenon of *luminous interference.* By it we explain the twinkling of the fixed stars. The different portions of the atmosphere continually varying in density, realize the conditions of the phenomenon of interference, and thus intercept some of the rays composing the white light of the stars, leaving only the other rays to reach our eyes, and present them with a feeble and differently-coloured image.

The reason why the planets do not twinkle is that they appear of a certain magnitude.

The aspect of the heavens varies with the position of the observer. Let us suppose him stationed at one of the poles of the earth—the north pole, for instance. In this situation his zenith will be the northern celestial pole, and his rational horizon will coincide with the equator. All the stars whose declination is northern, that is to say, all those included between the equator and the north pole, will appear to move in circles parallel to the horizon. Those whose place is in the equator, will sweep the horizon, and all those whose declination is southern will remain constantly invisible. The parallelism of all these motions to the horizon has obtained for this position, as we have already said, the name of *parallel* position of the sphere.

Now let us suppose the observer transported to the equator: his rational horizon will pass through the poles, and in this position he will perceive the stars during the whole time they employ in traversing half their diurnal circles, and the planes of all these circles will be perpendicular to the horizon. This is the *right* position of the sphere.

If the observer then move towards one of the poles—the northern, for example—this pole will appear gradually to rise above the horizon, and the south pole to sink below it in the same proportion. Suppose the observer removed, for instance, 30 degrees from the equator towards the north pole, his zenith will be C F, the great circle H O R will be his horizon, the plane of the equator E O Z will be 30 degrees removed from the zenith F, and consequently 60 degrees distant from the horizon. The pole P will be elevated 30 degrees, measured by the angle H C P, and the pole P′ will be depressed by the same quantity below this plane. It follows from this construction, that the distance from the zenith to the equator, or the *latitude* of the place, is always equal to the elevation of the pole above the horizon. In this situation the circles described by the stars are inclined to the horizon; whence this position of the sphere derives its name of *oblique*.

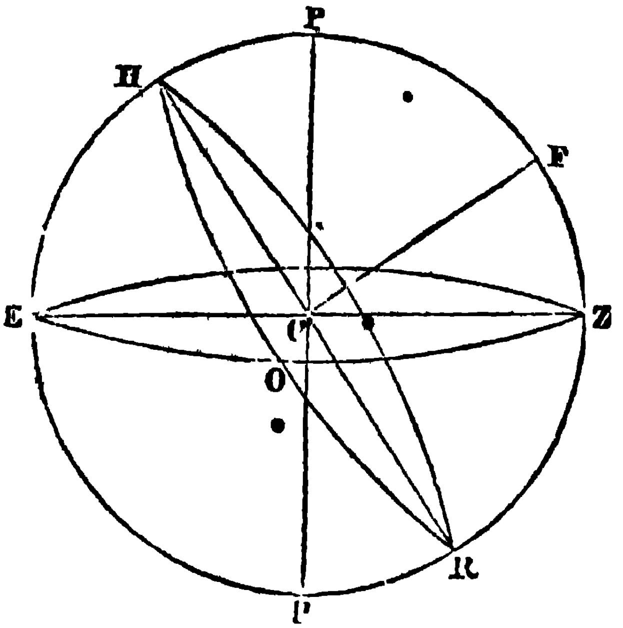

Fig. 11.

In following the stars of the sphere in their course, we have seen them all rise successively above the horizon, and then sink below it. At what point is it that the star will cease to rise?* How is this to be determined?

There are several methods of arriving at the solution of this question: the following, founded upon *corresponding heights of the sun*, is perhaps the simplest.

Upon a surface exactly horizontal (of which we can assure ourselves by means of a spirit-level) we place a vertical style, from the foot of which as a centre we describe several circles on the horizontal surface. On each of these we mark the points corresponding to the extremities of the shadows projected by the sun at different heights before and after noon; we then divide the arc comprised between the two points which the shadow has marked on each circle, and thus we obtain a line which, passing through the foot of the style, determines the plane in which the sun is found, when he has reached the highest point in his course. This instrument is called the *gnomon*, and the plane which it serves to determine, the *meridian*, which passes through the zenith of the plane and through the poles.

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* Or, as English astronomers say, when will it *culminate*? that is, reach the highest point to which it can climb.—Trans.

Another method, also very simple, is that of the *measure of time;* but it requires the aid of a transit-instrument, or meridian-telescope, which we are the more induced to describe, as it is of frequent use amongst astronomers.

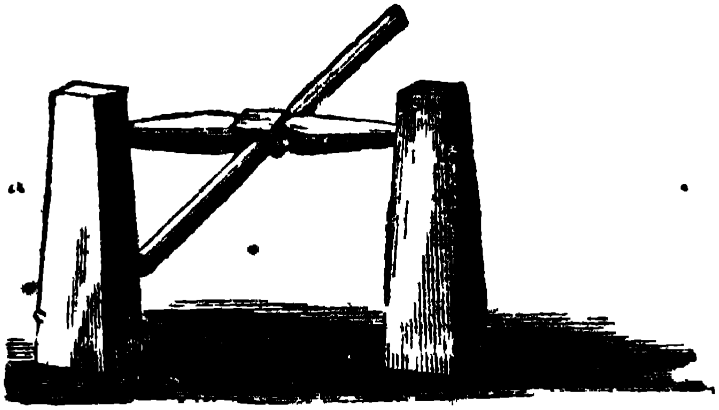

Fig. 12.

This instrument consists, like the usual astronomical refracting telescopes, of a cylindrical tube furnished with an object-glass and eye-glass. In the focus of its object-glass is placed a diaphragm pierced in the middle, and intended to prevent the passage of all the rays except those near the axis, so as to render the image more distinct. In the same situation are fixed, on a moveable metallic plate, extremely fine wires, dividing the field of view into four equal parts. In the micrometer these wires are usually of the number of five vertical and parallel, and one horizontal. This instrument, fixed with the utmost possible stability in upright supports, is so constructed as to be only capable of moving in one vertical plane.

To determine the meridian, the instrument is placed in a vertical plane, the telescope is directed upon a star constantly visible, the instants of its greatest and least heights are noted, and the time elapsed between the two transits of the star is counted with a very exact chronometer. Almost always, if we have chosen a vertical plane at hazard, we find a great difference between the two portions into which its course is thus divided, the one being greater than a semi-revolution, that is to say, than twelve hours sidereal time ; the other less. It will be sufficient to know this difference, to enable us by repeated essays gradually to adjust the instrument to the plane which shall accurately divide into two equal portions the diurnal circle of the star.

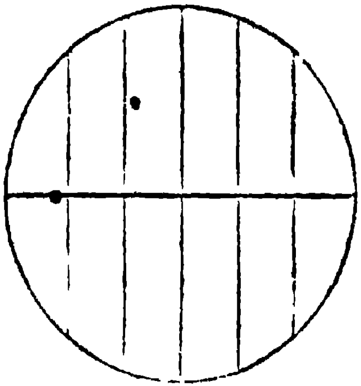
Fig. 13.

There are also several methods for fixing the positions of the stars. Two of these are particularly in use.

The first consists in measuring the angles formed by the vertical plane passing through each star with a meridian, to which we refer the distances of these stars.

We begin by fixing the altitude or height of the star S observed, on the vertical plane in which it is situated, by means of the *mural quadrant.* This is a sector furnished with a moveable telescope Tt, in whose focus there is a micrometer consisting only of two moveable wires, the one vertical, the other horizontal : the radius of the circle must be placed exactly vertically in the plane of the meridian, and must be set at O on the scale at the curved edge of the plate on which the radius moves. The vertical thread AB serves to direct the optic axis into the plane of the radius ; an indispensable precaution, in order that the arcs measured by the limb may be equal to those described by the optic axis. At the moment when the axis enters the field of the telescope, it is made to pass by means of a suitable mechanism along the horizontal wire, and when its centre touches the vertical wire, it is exactly in the plane of the meridian. We then read off upon the limb the arc SZ subtended by the angle formed by the vertical radius AZ and the visible ray: this angle is the zenith-distance, the complement of the meridian-altitude; the former being, in the figure, 50°, and the latter 40°.

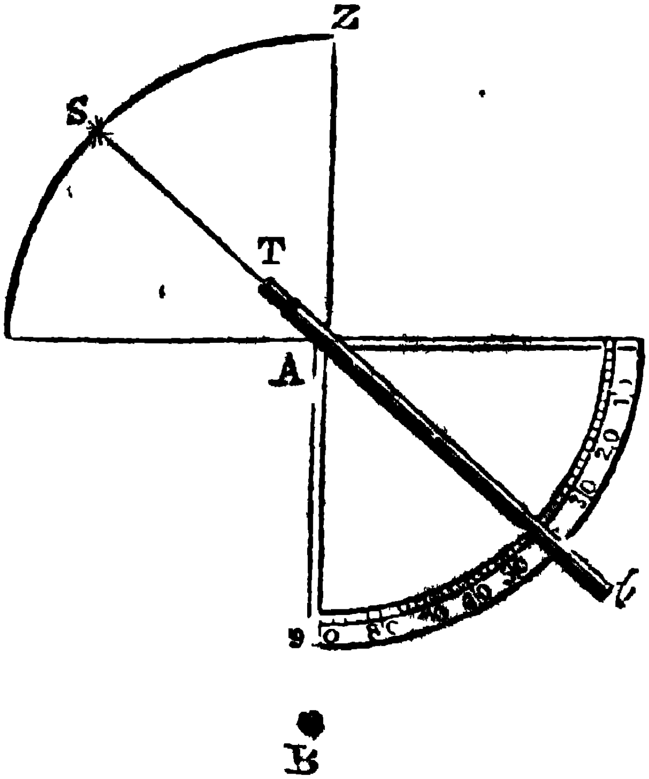

Fig. 14.

"The next thing to be known is the angle formed between the vertical of the observed star and the meridian; this angle is called the star's *azimuth*, and is either east or west. It may be found by accurately noting the time of its passage across the meridian, and the time of its being in the vertical where it is observed: the interval between these two times gives the value of the angle. This method, which is extremely simple, is pretty frequently employed.

The zenith-distance and the azimuth of a star, elements necessary for ascertaining its position, may also be obtained by means of an instrument called an entire or *mural* circle, which is sometimes connected with a *wall* (whence its name), as in the adjoining figure; but it sometimes consists of two graduated circles: one of which, horizontal, represents the equator; the other, furnished with a telescope having a micrometer, is vertical to the former, and moves freely upon an axis. At the moment we wish to observe the star, we bring the centre of the cross wires to bear on it, having first carefully adjusted the last-named circle in the vertical plane of the star. This circle then indicates the altitude of the star above the horizon, and its zenith-distance which is the complement of that quantity, whilst the horizontal or azimuthal circle marks the azimuth at the moment of the observation.

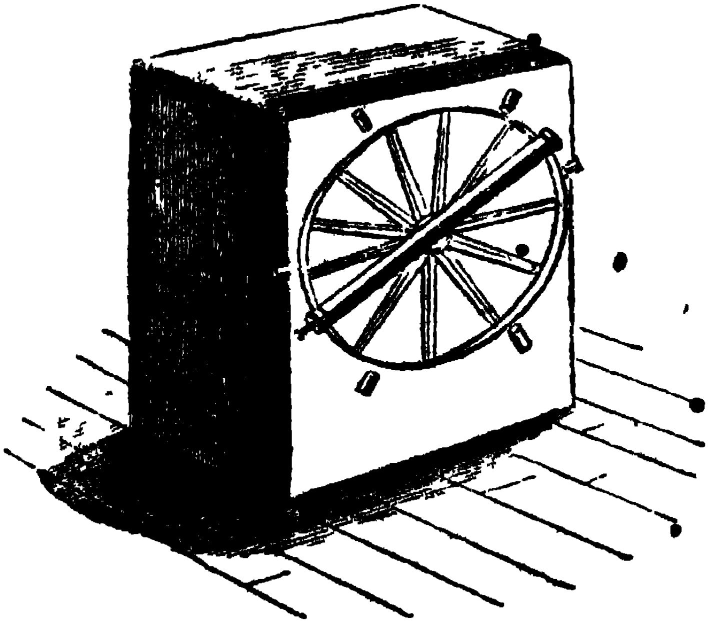

Fig. 15.

Zenith-distances and azimuths form, as we see, a system of angles, by means of which it is easy to fix the positions of the stars with extreme precision. But this method is subject to one inconvenience, which has led to its almost entire abandonment: this is, that the zenith and the azimuths varying as often as the observer changes his horizon and his meridian, there is thus no fixed point to which every observation may be referred, and there is no common point of comparison between the several positions. For this reason, the following method, called that of *right ascensions and declinations*, is generally preferred.

In this method it is enough to know the horary circle of the star, and its place in this circle.

The place of the star in the horary circle is determined by means of the instrument we have already described for measuring meridian altitudes. With this instrument we ascertain the distance of the star from the pole, and from this the complement thereof, its distance from the equator, which we term its declination; on this account horary circles are sometimes called *circles of declination.*

Declination is counted from 0 up to 90 degrees, and is either north or south in reference to the equator.

As for the position of the horary plane, it is determined by the angle it makes with a given horary plane. If the angle formed by the meeting of these planes be measured by an arc of the equator, this arc is what is called the *right ascension* of the star. It is determined by observing the time that elapses between the passage of the star across the meridian, and that of the horary plane selected to reckon from. Astronomers designate with the sign ♈ the point from which they begin to count right ascension; this is the point where the sun cuts the equator, when he ascends from the southern tropic towards the northern.

Right ascension then is the angle which the horary plane of a star forms with the meridian, at the moment when the point assumed in Aries ♈, that point in which the sun appears to us in Spring, is situated in the plane of the meridian. Right ascension is always counted from west to east, and from 0 up to 360 degrees, or an entire circumference. This system of lines for determining the positions of stars presents, it is obvious, many analogies with the preceding one; but it differs essentially from it in this respect, that the positions of the stars being indicated with relation to circles of the sphere invariably fixed, since they are in fact the celestial equator and a fixed meridian, observers, wherever situated on the earth's surface, may all refer their observations to it, and compare together the results they have obtained. Declination and right ascension being known, every relation of place and distance in the celestial sphere may be discovered.

The foregoing remarks will enable us to understand the method of obtaining a catalogue of stars by means of a transit, or any other suitable instrument. We determine the moment when any known star whatever passes the meridian; we note exactly the hour, minute, and second of the passage, reckoning from 0 on the astronomical clock. We do the same by all the other stars, as they arrive at the plane of the meridian. Thus we become acquainted with the differences of their right ascensions: we learn also the altitude of each of them. Having obtained these data, we can easily lay down their relative positions to each other, and we shall thus possess a celestial map, on which will be traced the various groups of stars forming the constellations. The first celestial maps were of great antiquity. Hipparchus was the first who constructed them, and as the relative distances of the stars have undergone no very sensible change since the earliest observations, they may always be employed in studying the heavens.

The same point which serves to count right ascension from, is also the starting-point of sidereal time; that is, we count $0^h\ 0'\ 0''$ sidereal time, at the moment of meridian-transit.

It will now be readily conceived that nothing can be more easy than to ascertain the hour of the day in sidereal time, the elevation of the pole in the place occupied by the observer being previously known. It will be enough to observe the zenith distance of a known star, and to calculate its horary angle, counted, for instance, from the superior meridian, in the direction of the diurnal movement from 0 to 360 degrees, adding this angle to the right ascension of the star, and rejecting entire circumferences, if there be any. The remainder converted into time will express the distance of the meridian from the point of the heavens assumed as the starting-point, that is to say, the hour in sidereal time.

LECTURE IV.

THE FIXED STARS.

UNDER this denomination, we have said, are comprised all those bodies of the sphere which appear always to retain their relative positions: which *appear,* we say, because modern observations, particularly those of Herschel, have proved the occurrence of changes in their mutual relations, whence we must conclude that the fixed stars are also subjected to motions, very slow indeed, and scarcely perceptible. Their number at the first view appears immense, because they are scattered and confused, and cannot all be included together in the field of vision. We may easily satisfy ourselves that the number of those that can be seen with the naked eye is very limited, and amounts to scarcely more than a few thousands. All we need do is to take a portion of the heavens and count those it contains: we shall hardly be able to see more than 500 at a time, but with the help of telescopes their number increases beyond expression.

Their distribution in the heavens in groups or masses has suggested the idea of arranging them into constellations. These, as we have already seen, are systems of stars distinguished from each other by letters and figures. Hipparchus has bequeathed us a general table of the constellations reckoned in his time: they are forty-eight in number; twelve in the zodiac, twenty-one north, and fifteen south of it. In the present day, their number is considerably augmented. At the end of this volume will be found a table of the constellations, with the number of stars included in each.

Kepler threw out a very ingenious suggestion respecting the dimensions and the distances of the fixed stars. He remarks that there are on the surface of a sphere only thirteen points equally remote from each other and from the centre; and supposing the nearest fixed stars to be as distant from each other as they are from the sun, he comes to this conclusion, that there are rigorously but thirteen stars of the first magnitude. At twice the distance from the sun there may be four times as many, and so on. This method of calculation agrees pretty nearly with the number of the stars of the first, second, and third magnitudes.

In clear weather, when the stars are very distinct, we see in several parts of the celestial sphere whitish spots shedding a faint light. On examining them with an instrument of high magnifying powers, we discover in them a multitude of little stars set very close together: it is the light they give that occasions the observed spots. The milky way, that broad zone spanning the vault of the heavens, is itself but an assemblage of similar nebulæ. Herschel, who observed them with a powerful telescope, speaks of them in these terms:—

"A very remarkable circumstance attending the nebulæ and clusters of stars is, that they are arranged in strata, which seem to run on to a great length, and some of them I have been already able to pursue so as to guess pretty well at their form and direction. It is probable enough, that they may surround the whole apparent sphere of the heavens, not unlike the milky way, which is undoubtedly nothing but a stratum of fixed stars. As this latter immense starry bed is not of equal breadth or lustre in every part, nor runs in one straight direction, but is curved and even divided into two streams along a very considerable portion of it, we may likewise expect the greatest variety in the clusters of the stars and nebulæ. One of these nebular beds is so rich, that in passing through a section of it, only in the time of thirty-six minutes, I detected no less than thirty-one nebulæ, all distinctly visible upon a fine blue sky. Their situation and shape, as well as condition, seem to denote the greatest variety imaginable. In another stratum, or perhaps a different branch of the former, I have seen double and treble nebulæ, variously arranged; large ones, with small seeming attendants; narrow, but much extended; lucid nebulæ, or bright dashes; some of the shape of a fan, resembling an electric brush, issuing from a lucid point; others of the cometic shape, with a seeming nucleus in the centre; or like cloudy stars surrounded with an atmosphere; a different sort again contain a nebulosity of the milky kind, like that wonderful inexplicable phenomenon about θ Orionis; while others shine with a fainter mottled kind of light, which denotes their being resolvable into stars.

"It is very probable that the great stratum called the milky way, is that in which the sun is placed, though perhaps not in the very centre of its thickness. We gather this from the appearance of the galaxy, which seems to encompass the whole heavens, as it must certainly do if the sun is within the same. For suppose a number of stars arranged between two parallel planes, indefinitely extended every way, but at a given considerable distance from each other; and calling this a sidereal stratum, an eye placed somewhere within it will see all the stars in the direction of the planes of the stratum projected into a great circle, which will appear lucid on account of the accumulation of the stars; while the rest of the heavens at the sides will only seem to be scattered over with constellations, more or less crowded, according to the distance of the planes, or number of stars contained in the thickness or sides of the stratum."

We are now in a condition to appreciate the position occupied by our little planet in this vast system. Let us take a star of this immense congeries, and compare it with the innumerable quantity of the others; and that we may judge the better let us examine it at first with the naked eye. "The stars of the first magnitude, being in all probability the nearest, will furnish us with a step to begin our scale. Setting off, therefore, with the distance of Sirius or Arcturus for instance, as unity, we will at present suppose, that those of the second magnitude are at double, and those of the third at treble the distance, and so forth. It is not necessary critically to examine what quantity of light, or magnitude of a star, entitles it to be estimated of such or such a proportional distance, as the common coarse estimation will answer our present purpose as well; taking it then for granted, that a star of the seventh magnitude is about seven times as far as one of the first, it follows that an observer who is inclosed in a globular cluster of stars, and not far from the centre, will never be able, with the naked eye, to see to the end of it: for since he can only extend his view to about seven times the distance of Sirius, it cannot be expected that his eyes should reach the border of the cluster, which has perhaps not less than fifty stars in depth everywhere around him. The whole universe, therefore, will to him be comprised in a set of constellations richly ornamented with scattered stars of all sizes. Or if the united brightness of a neighbouring cluster of stars should in a remarkably clear night reach his sight, it will put on the appearance of a small, faint, whitish, nebulous cloud, not to be perceived without the greatest attention. Allowing him now the use of a common telescope, he now increases his power of vision, and applying himself to a close observation, finds that the milky way is indeed no other than a collection of very small stars. He perceives that those objects, which had been called nebulæ, are evidently nothing but clusters of stars."

Herschel remarks that in the most thickly-set portion of the milky way, there are fields of view, embracing only a few minutes, which contain as many as 588 stars; that in a quarter of an hour he has seen 116,000 pass through the field of his telescope, the opening of which was but 15′; and that at another time he has seen 258,000 pass it. Every improvement he made in his telescopes enabled him to discover still more stars; and it does not appear that there are any more limits to their number than to the extent of the universe.

Our sun is probably but a fixed star, since if it was transported to a distance, within which we shall presently demonstrate that the stars cannot be situated, it would have absolutely such an appearance. What other conclusion can be drawn from this but that the stars, which shine with their own light, since their distances are incommensurable, are comparable to the sun in brilliancy and in volume; that they must be as distant from each other as they are from us; and that analogy would show that, like our sun, they disperse light and heat to the planetary systems that gravitate round them?

Herschel thinks that our sun, like the majority of the stars. has a direct progressive motion towards the constellation Hercules, in which it carries all our planetary system along with it. He remarks that the apparent motions of forty-four out of fifty-six stars he studied, are nearly such as would be produced by a real motion of this kind in the solar system, and that the brilliant stars of Sirius and Arcturus, which are probably the nearest to us, exhibit, as they should do according to the theory, the greatest apparent motions. The star Castor appears, when viewed by the telescope, to be formed of two stars of nearly equal size,* and though they have an apparent motion, it has not been possible to detect in them a variation of their relative distance, amounting to a single second; a fact which it is easy to comprehend, if their apparent motions are owing only to a real motion in the sun.

On looking over the catalogues of stars left us by the ancients, we are struck by a very singular fact: some of these stars have changed their lustre in a manner more or less remarkable; and whilst some have made their appearance that had never before been seen, others have disappeared to return again, or in some instances without ever re-appearing. These astonishing phenomena have occurred at all periods. The following is an interesting extract from Halley on these extraordinary changes.

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* This is also the case with the pole-star and some others. In viewing these double stars, a singular phenomenon discovers itself, first noticed by Herschel: some of them are of different colours, which, as the images are so near each other, cannot arise from any defect in the telescope. α Herculis is double, the larger star is red, the smaller blue; ε Lyræ is composed of four stars, three white and one red; γ Andromedæ is double, the larger reddish white, the smaller a fine sky-blue. Some single stars evidently differ in their colour; Aldebaran is red, Sirius brilliant white.—(*Brinkley, Elem. Ast.*)

The first new star of Cassiopea "was not seen by Cornelius Gemma, on the 8th of November, 1572, who says, he that night considered that part of the heavens in a very serene sky, and saw it not, but that the next night, November 9, it appeared with a splendour surpassing all the fixed stars, and scarcely less bright than Venus. This was seen by Tycho-Brahé before the 11th of the same month; but from thence he assures us it gradually decreased, and died away, so as in March, 1574, after sixteen months, to be no longer visible; and at this day no signs of it remain. The place thereof in the sphere of fixed stars, by the accurate observations of the same Tycho, was 0^{s} 9° 17′ right ascension, with 53° 45′ north latitude.

"Such another star was seen and observed by the scholars of Kepler to begin to appear on September 30, 1604, old style, which was not to be seen the day before: but it broke out at once with a lustre surpassing that of Jupiter, and like the former it died gradually away, and in much about the same time disappeared totally, there remaining no footsteps thereof in 1605. This was near the ecliptic, following the right leg of Serpentarius, and by the observations of Kepler and others, was in 7^{s} 20° 0′ right ascension, with north latitude 1° 56′. These two seem to be a distinct species from the rest, and nothing like them has appeared since.

"But between them, viz. in the year 1596, we have the first account of the wonderful star *in collo* Ceti, seen by David Fabricius, on the 3rd of August, old style, as bright as a star of the third magnitude, which has been since found to appear and disappear periodically; its period being precisely enough seven revolutions in six years, though it return not always with the same lustre, nor is it ever totally extinguished, but may at all times be seen with a six-foot tube. This was singular in its kind, till that *in collo* Cygni was discovered. It precedes the first star of Aries 1° 40′, with 15° 57′ south latitude.

"Another new star was first observed by Will. Jansonius in the year 1600, *in pectore* or rather *in eductione colli* Cygni, which exceeded not the third magnitude. This having continued some years, became at length so small, as to be thought by some to disappear entirely; but in the years 1657-8-9, it again rose to the third magnitude, though soon after it decayed by degrees to the fifth or sixth magnitude, and at this day is to be seen as such in 9^s 18° 38′ right ascension, with 55° 29′ north latitude.

"A fifth new star was first seen and observed by Hevelius, in the year 1670, on July 15, old style, as a star of the third magnitude; but by the beginning of October was scarcely to be perceived by the naked eye. In April following, it was again as bright as before, or rather greater than that of the third magnitude, yet wholly disappeared about the middle of August. The next year, in March, 1672, it was again seen, but not exceeding the sixth magnitude, since when it has been no further visible, though we have frequently sought for its return: its place is 9^s 3° 17′ right ascension, and has north lat. 47° 28′.

"The sixth and the last is that discovered by Mr. G. Kirch, in the year 1686, and its period determined to be 404½ days: though it rarely exceeds the fifth magnitude, yet it is very regular in its returns, as we found in the year 1714. Since then we have watched, as the absence of the moon and the clearness of the weather would permit, to catch the first beginning of its appearance in a six-foot tube: that bearing a very great aperture discovers most minute stars. And on June the 15th last, it was first perceived like one of the very least telescopical stars; but in the rest of that month, and in July, it gradually increased, so as to become in August visible to the naked eye, and so it continued all the month of September. After that it again died away by degrees, and on the 8th of December, at night, was scarcely discernible by the tube, and as near as could be guessed, equal to what it was at its first appearance on June 15: so that this year it has been seen in all near six months, which is but little less than half its period; and the middle and consequently the greatest brightness falls about the 10th of September."

Two classes have been formed of the stars, supposed in the last century to be *variable*. In the first are those which are certainly so; in the second those which are only presumed to be so. The first are twelve in number, from the first to the fourth magnitude, including that which appeared in Cassiopea in 1572, and that which was seen in 1604 in Serpentarius. The second class contains thirty, from the first to the seventh magnitude.

Conjecture has been exhausted to account for these surprising changes. Newton thought that the transient vivacity of their lustre was owing to an increase of combustible matter, produced by the fall of a comet. This system of Newton's, which would have it that comets are intended to feed the combustion of the stars, precisely in the same way as so many pieces of fuel which we throw into the fire, is but little in harmony with the means employed by nature, and with the probable mode of combustion of the celestial bodies, which can hardly be owing to any other than electrical agency. Maupertuis supposes that the stars have such a rapid rotary motion, that the centrifugal force must have given them the figure of a spheroid so greatly flattened as to be reduced to a circular plane like a millstone; and that in this way they necessarily appear to us very brilliant, when their motions so incline them that they present to us the faces of their disks, while on the other hand they are hardly or not at all visible to us when their edges alone are turned towards us. Others have thought that these changes were produced by dark spots spread over the surfaces of the stars, or else that these bodies revolve in orbits so vast, that, like the comets, they are only visible when in the points of their orbits the nearest to us. The more probable opinion respecting these periodic stars is, that they have dark faces.

These observations suggest a reflection. Our sun, we have said, is a star. Has it never undergone analogous variations? and if it has experienced some of these great vicissitudes, what prodigious consequences must have resulted from them! These considerations are perhaps deserving of the serious attention of geologists in their search after the causes of those tremendous catastrophes of which our globe everywhere affords traces.

To close the subject of this lecture, it now remains for us to form, if possible, an idea of the distance that separates us from the fixed stars. Before engaging in this problem, we shall lay down some indispensable preliminaries.

The angle subtended by an object varies inversely as the distance of the object from the spectator's eye. This is one of the most elementary propositions in geometry.

Again, trigonometry makes known the relations that exist between the dimensions of a body, its distance, and the angle it subtends: thus an object which subtends an angle of 1° is at 57·38 times its dimensions; if the angle it subtends is 1′, it is at 3,438 times its dimensions; and 206,000 times if the angle subtended is 1″.

This being established, it is easy to conceive that, the diameter of the earth being known, if we knew the angle it subtends when viewed from the stars, we should thereby at once have the distance of these stars. This angle is what is called the *parallax*. To find it we employ a method similar to that which is had recourse to for finding the distance between terrestrial objects. It consists in taking a base of a known length, and measuring the angles formed with it at its extremities by the visual rays proceeding from the object whose distance is required. These angles being measured, their sum is subtracted from 180°; the remainder is the angle sought, according to that very pregnant proposition of geometry, that the three angles of a triangle are always equal to two right angles.

But when we proceed in this way, taking for our base the radius or diameter of the earth, the parallax it gives is not appreciable in relation to the stars; which shows that the diameter of the earth is a quantity altogether imperceptible, when compared with the distance that separates us from the fixed stars.

Since the diameter of the earth, about 8,000 miles, is nothing compared to the distance of the fixed stars, to what standard of comparison shall we have recourse to measure the latter? To one which, perhaps, will suffice; the great diameter of the terrestrial orbit, a length of 190,000,000 miles. This is what is called the *great parallax*, or the *annual parallax*. Hook, Flamsteed, and Bradley, observed with the zenith-sector, at the vernal and autumnal equinoxes, the passage of γ Draconis across the perpendicular telescope, expecting that the diameter of the earth's orbit would make an angle or parallax with it. Their expectation was not realized: the angle was not appreciable. And yet, if the annual parallax of these stars was only one second, they would still be more than 140,000 000,000,000 miles from us, and we might measure their volumes. Can anything more strikingly impress us with ideas of the immensity of space, especially if we reflect that these millions of stars strewed before our eyes are all at immeasurable distances from each other?

LECTURE V.

DISTANCES OF THE PLANETS; THE SUN—PHYSICAL CONSTITUTION OF THE MOON—PHYSICAL CONSTITUTION OF AEROLITES.

Distances of the Planets.

HOWEVER great the magnifying power of the instrument we employ, the apparent diameter of the fixed stars is never enlarged. The planets, on the contrary, exhibit disks, whose diameters increase with the power of the instrument with which we observe them. This difference presents us at once with a convincing proof, that they are much nearer to us than the fixed stars; and the micrometer proves that this distance varies, since it exhibits variations in their apparent diameters.

The moon, whose distance from the earth observations of this kind proved to be necessarily very small, was early subjected to the investigations of modern geometry. MM. Lacaille and Lalande betook themselves, the one to Berlin, the other to the Cape of Good Hope, to determine the moon's parallax. We have already explained this term as signifying the angle contained between two visual rays proceeding from a star to each extremity of the earth's radius. They found this angle (for the centre of the moon's disk) to be 1°, which gives for the moon's mean distance from the earth about sixty terrestrial radii, or 230,000 miles. The moon's diameter is about one-fourth of that of the earth, and its bulk about one-fiftieth.

The possible amount of error in this method of computing the distance may be half a second for each of the angles measured at Berlin and the Cape; consequently one second for the entire result; that is to say, the 3,600th part of the distance. This method must always be subject to this amount of error, because we cannot be sure of an angle within less than half a second.

The sun's parallax is 8″·6, and its mean distance is 94½ millions of miles. Its diameter is to that of the earth in the proportion of 111 to 1, and its bulk in the proportion of 1,300,000 to 1.

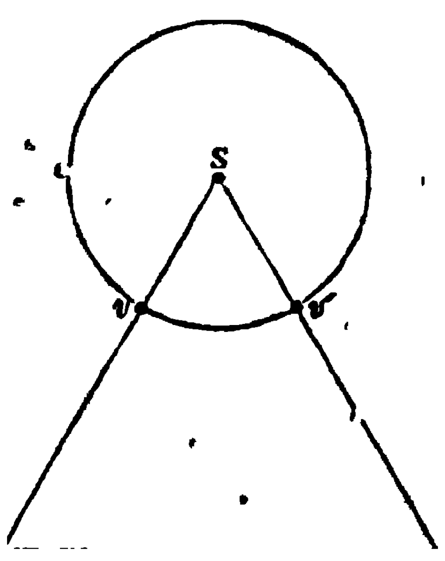

Fig. 16.

The sun's parallax is known within a tenth of a second; a much closer approximation than we have been able to obtain by the ordinary method. It has been made by another method which we shall explain.

It is furnished by the transits of Venus across the sun's disk. Let S be the sun, AB the earth's radius, and *vv′* Venus describing her orbit round the sun. Let us now suppose that two observers placed, the one at A, the other at B, observe and accurately note the different phases of the conjunction ; the difference of their results will give the time occupied by Venus in passing over the circular arc *vv'*, which arc is itself the measure of the sun's parallax. This operation, which we here present in so simple a form, is rendered complicated by the motions of the earth, and other particulars, for which it is necessary to make due allowance in order to obtain a result entirely divested of error.

The distances and volumes of the other planets have been determined by similar means : we shall give the results when we come to speak of them in detail. We may pause, however, to remark the singular numerical relations existing between the distances of the planets from each other. If we take the following numbers, 0, 3, 6, 12, 24, 48, 96, 192, and then add to each of them the number 4, we shall have 4, 7, 10, 16. 28, 52, 100, 196, expressing the order and proportion of the planets' distances from the sun, thus :

0 .	3 .	6 .	12 .	24 .	48 .	96 .	192
4	7	10	16	28	52	100	196
☿	♀	⊕	♂	⚳	♃	♄	♅

Professor Bode, of Berlin, in the year 1772, considering these relations, and observing in them a void between 16 and 52, ventured to predict the discovery of the new planets ; and it was this conjecture that guided the investigations of the astronomers who discovered them.

The Sun ☉.

We have just seen that the sun is an immense globe, 1,300,000 times greater than the earth, and that [illegible] mean distance from us is 94½ millions of miles. We shall see by-and-by how gravity supplies us with the means of determining its density and its weight.

We have already said, on the authority of Herschel, that this star is probably carried with all his train of planets, towards the constellation Hercules: it has, moreover, a motion of rotation upon its own axis, which it accomplishes in twenty-five days. This is proved by observing the spots on its surface. The manner in which these spots move, and the various aspects they assume, according as they present themselves to us obliquely or with their faces towards us, leave no manner of doubt that they are inherent in the surface of the sun, and that this star is a spherical body. We omit for the present its apparent motion in the plane of the ecliptic: further on we shall see it is the result of the transference of the earth to the different points of its orbit.

Physical constitution of the Sun.

The sun, we have said, exhibits spots on its surface; some of these are obscure, others luminous; the latter have acquired the names of *faculæ*, and the former of *maculæ*. Their form is very irregular, their duration very variable, and they are commonly surrounded by a penumbra. They are always comprised within a zone, whose extent varies north and south of the solar equator.

Many conjectures have been offered in explanation of these spots. Some have supposed that the sun, from which so vast a quantity of light and heat is incessantly emanating, is a body in a state of combustion, and that the dark spots are nothing else than scoriæ floating on its surface. The faculæ, on the contrary, they suppose due to volcanic eruptions from the liquified mass. The grand objection to this hypothesis is, that it does not suffice to explain the phenomena: it has not obtained admission amongst astronomers. The opinion most in favour in the present day, regards the sun as consisting of an obscure and solid nucleus, enveloped by two atmospheres—the one obscure, the other luminous. In this view of the case, the appearance of the spots is explained by ruptures occurring in the atmospheres, and exposing the globe of the sun to view. The penumbra is the extremity of the inner and dark atmosphere, the rent in which is not so wide as in the luminous one, and which is seen round the opening that exposes the central nucleus.

This opinion, however strange it may appear, has the advantage of perfectly explaining all the phenomena, and it acquires a high degree of probability from the consideration, that the incandescent substance of the sun cannot be either a solid or a liquid, but is necessarily a gas.

It is an established fact, that rays of light, issuing from a solid or liquid sphere in a state of incandescence, possess the properties of polarization, whilst those emanating from incandescent gases are devoid of them. From the application of this principle to experiments made on solar light, has been derived the conclusion we have already stated; which refers to the *corpuscular* theory.

These experiments are made by means of a very ingenious instrument, the principle of whose construction is founded on the properties of polarized light. It is a telescope furnished with a piece of crystal, and presenting in its focus, when we look at the sun, two coloured images. A very simple mechanism enables us to cause the one or the other of these images to recede or advance, or even to cause one of them to cover the other wholly or partially. This telescope affords proof that the light of the sun's edges is as intense as that of its centre: for if the two images of the sun be made to lap over each other, so that the edge of the one may be upon the centre of the other, perfectly white light will be produced at the points of coincidence. Hence it follows, 1. That the edges of the sun possess a light as intense as the centre: 2. That the colours of the two images, produced by the telescope, are complementary the one to the other.

But from the fact that the light from the edges of the sun's disk is as intense as that from the centre, there follows another consequence; namely, that the sun has no other atmosphere outside the luminous one; for otherwise, the light of the edges, having a deeper layer to penetrate, would be found more weakened.

What is the nature of the light we derive from the sun? This question has long divided natural philosophers.

Some, supported by the authority of Newton, maintained that the sun, as well as all luminous bodies, has the property of discharging exceedingly minute particles of its substance with prodigious velocity : this is the theory of *emission.* Others, on the contrary, supposed that the phenomenon of light is produced by the vibrations of a fluid called ether, diffused through all nature, and set in motion by the presence of luminous bodies : this is the theory of *vibrations*, or the *undulatory* theory. It is nowadays universally received ; for it is impossible to conceive how a body should incessantly discharge portions of its substance without losing anything of its bulk and brilliancy. But the greatest defect of the theory of emission, is that it does not in the present day satisfy all the conditions ; whereas the other combines in its favour every probability, especially since recent discoveries have manifested evidence of the most intimate relations between the cause that produces electrical phenomena, and that which gives origin to light.

M Pouillet proposed to himself the problem of determining the temperature of the sun's rays. Let us imagine, he says, a sphere of ice with an opening which will admit of a thermometer being inserted, and reaching its centre, where it will maintain itself at a temperature of 32° of Fahrenheit. Suppose we cause rays of light to fall on the thermometer, it will acquire warmth, and will rise a certain quantity. Now, if we know the distance from the luminous body to the thermometer, the proportion that the opening by which the rays of light have had admission bears to the circumference of the sphere, and the quantity by which the thermometer has risen, we can calculate the quantity of heat sent to the instrument by the incandescent body. Thus, whatever be the distance. provided it be known, it will always be easy to come at the quantity of heat supplied, by means of the thermometer.

M. Pouillet found by this method, that his thermometer, placed under the circumstances described, never rose more than seven degrees and a half, and never fell lower than six degrees, which gave him a mean temperature of about 1,200 degrees for the solar rays.

It has likewise been asked, whether the rays of light —whose velocity is enormous, since, as we shall show, it amounts to nearly 200,000 miles in a second—have any appreciable impulsive force : but the most delicate experiments have detected nothing of the kind.

Some very remarkable observations have been, of late years, made in reference to the sun's light, during the time of a total eclipse. Several *rose-coloured* protuberances have been seen to project beyond the dark limb of the moon, which have been compared by some persons to flames, and by others to mountains. Now it has been reasonably supposed that these appearances are only cloudy masses of a very rare character, owing their support, and probably their existence, to the gaseous atmosphere already referred to.

The Moon ☽.

The moon, we have seen, is but the fiftieth part of the bulk of the earth, and its mean distance is but 237,000 miles ; so that with an instrument which magnifies one thousand times, we can see her as she would appear to the naked eye if she were only 237 miles off.

The moon's motions are very complicated, and for a long time greatly embarrassed astronomers. She moves in an ellipse, of which the earth occupies one of the foci, and which she describes in about 29½ days. She is at the same time carried along by the earth in its revolution round the sun ; and whilst the earth occupies a year in its revolution, the moon has already traversed her own orbit thirteen times and a half. She turns upon her axis precisely in the same time as she takes to revolve round the earth ; this is the reason why she always presents to us the same face.

From the combined effects of these motions result the moon's phases, that is to say, the different aspects under which we see this planet at different periods of her course. Thus let S be the sun, and T the earth, and let us see what will be the appearance of the moon. When it is at A in conjunction with the sun, it will present to the earth its unilluminated half; and, if projected on the disk of the sun, in a solar eclipse, will appear as at *a*; otherwise, the moon, in conjunction, is never seen. Arrived at B, after having described the eighth part of its orbit from the conjunction, it will present to the earth the fourth of its illuminated portion, and will be seen under the aspect it wears at *b*. At C it will have described the fourth part of its orbit, and will exhibit half its enlightened part, as at *c*. At D it will show more than half its illuminated side, as at *d*, and it will show it completely at E, as repvesented at *e*. Setting out from E, it will begin to wane, and will present the same phenomena, but in an inverse order, as shown in the figure, where the interior circle exhibits the moon as it would appear to a spectator placed on the sun, and the exterior circle as it is actually seen from the earth.

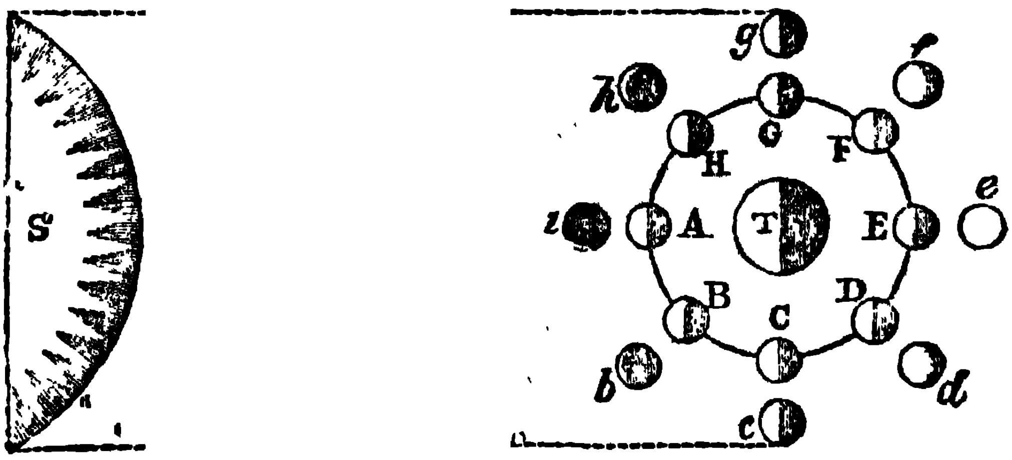

Fig. 17.

Such are the different phases which the moon describes in the space of 29½ days. When full, that is, when she presents the entire of her illuminated disk to the earth, she is said to be in *opposition* to the sun; when the moon is new, that is, when she presents her obscure portion to the earth, and is consequently invisible, she is said to be in *conjunction*: these two positions are called *syzygies*. It is in these positions that eclipses of the sun and moon occur, as we shall see by-and-by. Lastly, the moon is in her first or her last quarter when she shows us half of her illuminated portion; and these positions are called *quadratures*, and the intermediate points between them and the syzygies are called *octants.*

The moon's motion is much more rapid than the apparent motion of the sun. In fact, the latter advances but a degree a day, whilst the moon's velocity is about thirteen times as great; whence her return to the meridian is every day retarded nearly, or about, one hour. To the difference in the velocity of these motions is owing the return of the conjunction after 29½ days.

The plane of the moon's orbit *dcba* is inclined to that of the ecliptic A*e*DC*f*B at an angle measuring in the mean 5° 8′ 49″: the points of intersection of these planes are called *nodes,* the one *ascending* ☊ *e,* that from which the moon rises towards the north pole; the other *descending* ☋ *f,* that from which it sinks towards the south pole. The line *ecaf* going across from one node to the other, is called *the line of the nodes,* which, in the accompanying figure, is seen in perspective.

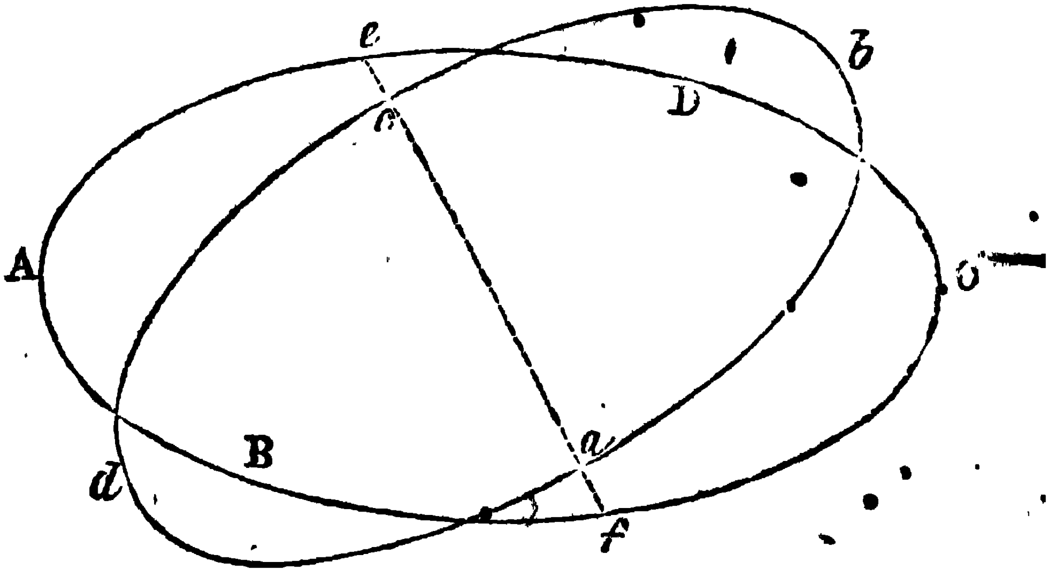

Fig. 18.

A fact that admits of no question, and that rests upon the most exact observation, proves that the moon's nodes move towards the west, and thus travel round the ecliptic in a direction contrary to the apparent course of the sun, or in the direction of his diurnal motion from east to west. Every year they complete about 19⅓°, which makes 1° every 19 days, or 1° 28′ every periodical lunar month, or lastly, an entire revolution of the heavens every 18⅔ years: more exactly, the nodes retrograde 19°·3286 annually, and complete their revolution of the ecliptic in 6788·54019 days. We find also that the *synodic revolution of the node* takes place in 346·61963 days; that is to say, that after this interval the sun is situated again in the moon's node. As the sun moves in a contrary direction to the node, they meet a little before the sun has completed an entire circuit of the heavens: this is the reason why this period is less than the year.

We have said that the rotary motion of the moon taking place within the same space of time as its revolution round the earth, it must, as it really does, always present to us the same face. We notice, however, from the observation of spots on its surface, that it sometimes shows us a little more, sometimes a little less, of one side or the other, as if it had a slight swaying motion like a balance. This is called the moon's *libration*, an expression that very well accords with the appearances observed, but which yet must not be understood in a strictly literal sense, for this apparent oscillation is but the effect of an optical illusion.

The moon's motion in her orbit varies as she approaches towards or recedes from the earth, whilst her motion of rotation is always uniform. Hence it follows, that during the period of acceleration, she shows on the east some parts of her surface not previously seen, whilst corresponding parts disappear on the west: the converse of this takes place during retardation. This is the phenomenon of *libration in longitude.*

Libration in latitude is the consequence of the moon's axis of rotation being inclined to her orbit, and of its always preserving its parallelism; whence it follows that the moon turns each of its poles to us alternately, and displays to us the spots situated about it.

Lastly, the *diurnal libration* of the moon will be understood upon considering, that, though the moon constantly turns the same hemisphere towards the centre of the earth, the spectator, who is removed from that point by the length of the earth's radius, perceives, when the moon is on the horizon, one portion the more of one side, and a corresponding portion the less of the other side.

Physical constitution of the Moon.

The moon's phases have shown us that she is not, like the sun, a self-luminous body, but that she is opaque, and shines by a borrowed light. As for the feeble lustre observable on her unilluminated portion, it arises from the light reflected upon her by the earth, and is called in French *la lumière cendrée* (the ashy light).*

When we observe the moon's disk with the naked eye, we observe on it a multitude of irregularities; but on examining it with a strong telescope, we observe on the part which is not yet illuminated by the sun during the first stages of its course, a great number of luminous points, which enlarge in proportion as the sun bears more directly on the part they occupy. Behind these points a deep shade is projected, which turns so as always to be in opposition to the sun. These brilliant points are the summits of high mountains, which receive the sun's rays before the less-elevated parts; and the obscure parts on which the shadows fall are cavities and valleys, which almost in every instance assume the form of craters. Geometry affords us the means of measuring the heights of these mountains; they are very elevated for the moon, but less so than the peaks of Himalaya. The shadows they project enable us to measure their elevation as well as the depth of the valleys; it is also to the presence of these asperities that we must attribute the jagged and irregular appearance occasionally presented by the moon's disk, the sun irradiating their summits, before his rays reach their bases.

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* In English this appearance is popularly called *the old moon in the new moon's arms.*—TRANS.

The moon has no atmosphere; or at least, if it has one, it is so rare that it does not differ sufficiently from a vacuum to cause any refraction of light. This is demonstrated by the immersions of stars; the latter in fact remain invisible, exactly the time they should do, which would not be the case if the moon had an atmosphere to refract the rays of light proceeding to us from these stars.

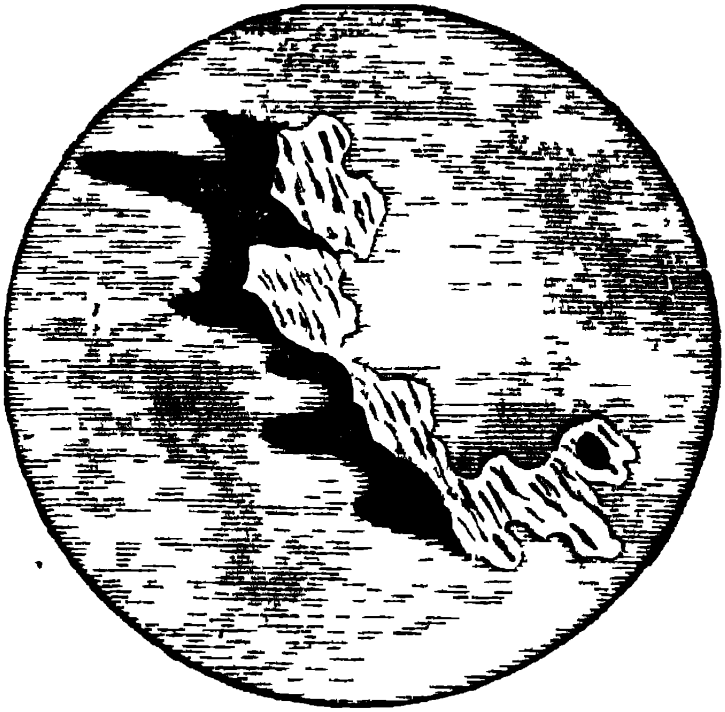

Fig. 19.

The axis of the moon being almost perpendicular to the ecliptic, the sun never sensibly quits its equator. it follows from this, that the moon enjoys no variety of seasons. But as it turns on its axis only once during its period of revolution, each of its days and each of its nights is equal to $14\frac{3}{4}$ times twenty-four of our hours; and what is very remarkable, one of its hemispheres is lighted by our earth in the absence of the sun, and has no night, while the other has one of $14\frac{3}{4}$ days' duration.

La Grange endeavoured to explain the reason why the moon's rotation and her revolution are isochronous. He supposed—and he extended this supposition to all the other satellites—that the face of the moon which is turned towards us is very much elongated in comparison with the other, and that it is the excess of its weight that makes it always turn towards the earth, in obedience to the attraction exercised by the latter.

The earth must appear to the inhabitants of the moon thirteen times greater than the moon does to us. It must present to them very regular phases, as will appear from inspection of fig. 17; and always invisible to one half of the moon, it is continually seen from the middle of the other half.

Whilst the earth turns on its axis, the aspect it presents to the moon must be very various. Our seas, continents, forests, and islands, must appear as so many spots of different size and brilliancy, and the atmosphere with its clouds must further modify these appearances in endless variety.

We have already said that the sun is constantly in the moon's equator; from this it results that the inhabitants of this satellite have not the same means as we of computing time; in fact, we measure the year by the return of the equinoxes, while their days are always equal. Still they might measure it by observing our poles, which they see perfectly well, and one of which always begins to be enlightened, and the other to disappear, as often as the equinoxes return.

Endeavours too have been made to ascertain what are the properties of the rays which reach us from the moon; but the most delicate experiments have failed in detecting in this light either calorific or chemical properties. Though concentrated in the focus of the largest mirrors, it produces no sensible heating effect. To make this experiment, recourse has been had to a bent tube, the extremities of which terminate in two hollow globes filled with air, the one transparent, the other blackened, the middle space being occupied by a coloured fluid. In this instrument, when caloric is absorbed by it, the black ball takes up more than the other, and the air it encloses increasing in elasticity, the liquid is driven out. This instrument is so delicate that it indicates even the millionth of a degree; and yet in the experiment alluded to, it gave no result. The light reflected by the moon has therefore no sensible calorific properties. It has likewise been ascertained that it has no chemical properties; hydro-chlorate of silver, a substance that blackens instantly under the influence of solar light, has been exposed to the moon's rays without undergoing any change.

Credulity, however, has attributed to the light of the moon a great influence over agricultural produce, and "la lune rousse" still enjoys a dismal renown in our rural districts. It is it, they say, that freezes the still tender shoots, and exercises so fatal an influence over the whole range of vegetation. It is easy to acquit the moon of these misdeeds, of which she is indeed quite innocent. What in fact is this same "red moon?" It is that which begins in April and ends in May; that is, at a season of the year when the temperature is often only four, five, or six degrees above the freezing point. Now we know that plants lose by radiation at night a part of the heat they have received during the day, and experience has shown that this loss may amount to seven or eight degrees, when the weather is clear, that is, when there are no clouds to neutralize this radiation; for the clouds reciprocally radiate towards the earth, and serve besides the office of screens, to stop caloric, and prevent its dispersion into the higher regions of the atmosphere. The temperature of plants, which by day was but four or five degrees, may thus by radiation fall several degrees below zero, and then the plants will freeze. But, as the excessive radiation can only take place when the sky is unobstructed, and when the moon consequently is visible, the influence of this planet will have the credit of that which is but a regular effect of the variation of temperature. And, as if everything must concur to favour this delusion, it will be confirmed by the success of the precautions supposed to be taken against the malignant influence of the moon, precautions whose real merit is, that they resist radiation. Thus gardeners, to protect the young shoots from the red moon, cover them with straw or other matters, which, forming a screen, hinder, as on other occasions do the clouds, the process of radiation, and thus preserve the plants from the frost.

These accusations against the moon are not of modern origin: similar ones had been already adduced by the ancients, and Plutarch asserts that its light putrefies animal substances. It is very true that, if we place in an exposed situation two pieces of meat, and one of them be subjected to the moon's rays, while the other is protected from them by a screen or a cover, the former will be tainted with putrefaction much sooner than the other; but, in this case, as in the former, an effect is attributed to the moon that does not emanate from her, and with which her rays have nothing whatever to do. That the uncovered piece of meat putrefies sooner than the other, is owing to the fact, that, being cooled more by radiation, it imbibes a greater quantity of moisture; and that moisture is a source of decomposition to animal bodies, since we dry them to preserve them.

Another error no less ancient, and no less generally diffused, is that which attributes to the moon's phases, and to her passage through the different quarters, an influence on the variations of the atmosphere and the changes of the weather. This popular error, which we find supported by the most ancient authors, has no foundation. For, not to mention that we cannot see how the moon could be instrumental in producing such results, the most exact observations, made upon the most extensive and continuous scale, formally contradict this supposition. Changes of weather are not more frequent at the moon's quarterings than at any other period; on the contrary, if there be a difference, imperceptible it is true, it is in favour of the octants.

What then can be the cause of an error so long accredited? Probably the lack of impartial observations, the involuntary tendency of the human mind to take account only of facts favourable to its preconceived opinions, without any regard to those that are hostile to them. Thus, let a change of weather occur at the renewal of a quarter, one is struck by the coincidence, one dwells upon it, and leaves unnoticed twenty other changes of the moon unaccompanied by any variation in the atmosphere.

The authority of Theophrastus has been cited in the support of the opinion we are combating, an authority, be it said in passing, of no great weight in matters of science. But those who cite the passage in question should have marked that it involves a self-contradiction. For what says Theophrastus? That the new moon brings bad weather, the full moon fine, and that the weather changes at each quarter. So then, if the weather is bad at the new moon, it will be fine at the second quarter, consequently bad at the full moon, which is in contradiction with the words of the passage.

A modern writer, who published a book intended to defend popular opinions, has endeavoured to support the one we are reviewing upon scientific grounds; he has fallen, however, into gross errors. And if he obtained the results he looked for from his observations, the reason was that he had taken his measures so that it was impossible it should have been otherwise; since he extended his observations over a greater or less number of days, according as he had need of a greater or less number of atmospheric changes.

Finally, it has been asked whether it is not possible that aërolites come from the moon, and the conjecture has been supported, amongst other grounds, by observations, which would seem to prove that this planet possesses numerous volcanoes. We must remark, in the first place, that the appearance on the surface of the moon, at different intervals of time, of self-lustrous points, and the crater-like form presented by almost all the cavities observed, are not sufficient to establish the existence of volcanoes in the moon. For the rest, it is very true that, the existence of these volcanoes being admitted, stones might be shot from them with a force sufficient to carry them out of the sphere of the moon's attraction. It has been calculated that, for this purpose, no greater velocity would be needed than five and a half times that of a cannon-ball, and our volcanoes have sometimes thrown rocks which must have issued from their craters with a greater velocity than that, to reach the distance at which they fell. We shall take a review of the different hypotheses by which this astonishing phenomenon has been sought to be explained.

And first, we shall enumerate the general circumstances observed with regard to meteoric stones, and which the hypotheses ought to suffice to explain in order to gain admission.

Aërolites are usually conveyed by igneous meteors of the kind named *bolides*, or globes of fire. They are all composed of the same chemical constituents, almost in the same proportions. We find in them a considerable quantity of silex, and of iron, sulphur, nickel, manganese, and chrome. There fell some at Alaix, in Languedoc, which contained also a small quantity of carbon; but perhaps those which fell elsewhere had also contained some, which they had lost in passing through the atmosphere: for these stones endure such a degree of heat in passing through the air as must dissipate a considerable part of whatever volatile principles they may originally have possessed. It is of importance to observe that the iron and nickel they contain is in the metallic state, which is not the case in those aggregations of metals that are found on the surface of the earth. It is certain, moreover, that these stones themselves are not naturally to be found on any part of the surface of our globe. All those that are known have fallen from the air.

Such are the facts: the suggestions offered for their explanation may be reduced to the three following hypotheses:—

1. It has been supposed that aërolites were, like rain and hail, true meteors formed by aggregation in the atmosphere.

2. Chladni thought they were fragments of planets, or even themselves small planets, which, circulating in space, entered the terrestrial atmosphere, and gradually losing their velocity in consequence of the resistance of the air, fell at last, by attraction, to the surface of the earth.

Lastly, the author of the *Mécanique Céleste* has remarked, that aërolites might possibly derive their origin from some lunar volcano, which should fling them to a sufficient distance from the moon to enable them to become satellites to the earth, but satellites which, having so much the less mass, should be subject to so much the greater perturbations. If, after circulating for a longer or shorter period in space, the small body should at last be carried within the radius of the earth's atmosphere, its velocity would necessarily be impaired, as in the last hypothesis, and it would finally, by attraction, come to the ground.

Of these three theories, the first, which at the first glance appears the simplest and the most natural, is nevertheless the most improbable: it will not even bear examination.

For in fact, that aërolites should form by way of aggregation in the atmosphere, it would be necessary that their constituent elements should previously exist there. That water and hail are formed in the air, is owing to the fact that the latter is always charged with watery vapours, and that cold is enough to condense them: but the most exact analysis has never discovered in the air any of the constituent principles of meteoric stones. We find in it neither sulphur, nor silex, nor nickel, nor manganese, nor iron: there is even no proof that oxygen and azote, the constituent principles of atmospheric air, can dissolve such substances. But here we are met with an objection. All these analyses, it is said, are made with air taken from the surface of the earth: now who knows, but in the higher regions there may be gases capable of holding in solution the metals and the earths of which aërolites are formed? To this we reply, that air has been analyzed taken from the greatest elevations to which man has ascended, and that its composition has been found absolutely the same as that of the air on the surface; a result moreover which might have been anticipated, since it is a general law of the statics of gases, that they expand in time over the whole space which is open to them, and that when we lay one over another, several of different natures or specific gravities, they mingle at last together, so as to form a thoroughly homogeneous compound. If, therefore, there existed in the higher regions of the atmosphere gases capable of holding in solution earthy or metallic matters, we should necessarily see something of this on the surface of the earth; and since that is not the case, the objection we are combating must consequently be unfounded.

To this first impossibility are added several others. Though it were admitted that the constituent elements of aërolites really existed in the atmosphere, at all heights, and only escaped analysis because they are in such small quantity, it would still be necessary to explain, with such feeble and such dispersed elements, a sudden precipitation, yielding stones of several cwts., such as those preserved at Ensenheim, in Alsace; or 3,000 or 4,000 stones of various dimensions, like those which were separated and shot off by the L'aigle meteor. It would be necessary to assign the cause that combines the scattered globules, and forms them into a single mass. It is not affinity; for the elements composing aërolites are not in a state of combination, but simply agglomerated, and held together in juxta-position. And yet, if they are not subjected to any force, these little globules ought to fall separately as they are formed. It is in vain to object that they might be suspended for more or less time by a cause analogous to that, which, according to the ingenious opinion of Volta, balances the particles of hail between two clouds, so as to give them time to enlarge by the addition of new layers of ice. The fact still remains, that these latter have never been seen to amount to several cwts., though the elements that form hail are much more abundant in the air than those of aërolites are supposed to be. Besides, in Volta's theory, the suspension of hail in the atmosphere is attributed to the reciprocal action of electric clouds, a cause which cannot be in like manner adapted to the formation of aërolites, since the meteors that carry them sometimes burst in the clearest weather. Lastly, if aërolites were formed in the air like rain or hail, they would, like them, obey the laws of gravitation, and would fall to the earth in a right line, or at least without any other deviation from it than that occasioned by the force of the winds. But this is not the case. Aërolites exhibit in their fall a very considerable horizontal velocity, sometimes comparable to that with which the earth moves in its orbit. This alone would be sufficient completely to exclude the possibility of their formation in the atmosphere, even had not the chemical reasons we have stated already induced us to discountenance the idea.

The second hypothesis respecting the origin of these masses is much more plausible. There have lately been discovered such very small planets, that we must not revolt against admitting it as possible that still smaller may exist, and such that our meteoric stones might proceed from them. These little planets entering the atmosphere of the earth, and there gradually losing their velocity, would at last fall upon its surface; but that could not occur without a considerable compression of the air in front of the moving body, a pressure which might no doubt be sufficiently powerful to disengage such a quantity of caloric, that the stony mass might be heated to a high degree, and that its volatile elements might be inflamed. This hypothesis then accords perfectly with all the circumstances of the fall of meteoric stones, but it does not in any manner account for their identity of composition; or at least it can only explain it by supposing that all the planets small enough to form meteoric stones are absolutely of the same nature, and composed of the same elements, in the same proportions; a supposition at variance with observation as regards the earth, and which, extended to the other celestial bodies, becomes, if we consider the generality of their nature, excessively improbable.

On the contrary, this identity of chemical composition accords surprisingly with the last theory, which supposes these stones to issue from a volcano in the moon: for in this case it is enough to suppose that the lunar volcanoes only project such substances, or that they are peculiar to a single one of them, which alone has the power of emitting them with sufficient force to make them satellites of the earth; and this degree of force, which has been ascertained by calculation, is, as we have seen, very inconsiderable, because the moon is not surrounded with a resisting atmosphere. But, as we stated in the outset, though the existence of volcanoes in the moon is rendered probable by astronomical observations, it is not yet established. Otherwise, these volcanoes once admitted, the explanation of the phenomenon becomes a mere question of simple mechanics. We may imagine between the earth and the moon a certain surface marking the limits of the space, within which each of these bodies possesses a paramount attraction. This limit will be nearer to the moon than to the earth, because the former body is much the smaller. Once the stone discharged by the lunar volcano is arrived beyond this limit, a thing which may occur in an infinity of directions, it becomes a satellite of the earth, but a satellite which undergoes enormous perturbation on account of its small mass compared with those of the earth, the moon, and the sun, by which it is attracted. Should the effect of these perturbations once be to entangle it in the earth's atmosphere, the resistance of that atmosphere will soon exhaust its velocity, and it will fall to the earth as in the preceding case.

Thus we are led to see that the theory deriving aërolites from volcanoes in the moon, is the most probable of all, and hitherto the only one that satisfies all the phenomena observed; but we repeat, it is still but a simple hypothesis, and the existence of lunar volcanoes is in no wise demonstrated.

LECTURE VI.

INFERIOR PLANETS—MERCURY, PHYSICAL CONSTITUTION OF—VENUS, PHYSICAL CONSTITUTION OF—SUPERIOR PLANETS—MARS, PHYSICAL CONSTITUTION OF—ASTEROIDS.

Mercury ☿.

MERCURY is the nearest planet to the sun. It appears in the evening after sunset in the western region of the heavens, under the form of a small but very brilliant disk, at first difficult to distinguish on account of the twilight, but becoming more and more brilliant in proportion as its distance from the sun increases, until arrived at a certain limit, it seems for a while to remain motionless. This first part of its course is direct, like that of the others, but it is not long before it retraces its path and disappears entirely. Soon after this, it reappears in the morning in the east, some time before the rising of the sun, withdraws from it more and more up to a point, where it again becomes stationary, again to retrace its path, plunge into the sun's rays, and reappear anew after its setting.

The brief duration of its appearance arises from its closeness to the sun, from which it appears to be separated but from sixteen to twenty-nine degrees: its direct distance from this star is 37,143,000 miles: its apparent diameter is about seven minutes, nearly two-fifths that of the earth; while its real diameter is 3,200 miles. It turns on its axis in 24^{h} 5′ 3″, and accomplishes its orbit in 87^{d} 23^{h} 25′ 44″, with a velocity of 111,000 miles an hour. This orbit, which is always comprised within that of the earth, forms a very eccentric ellipse, very much inclined to the plane of the planet's equator, and making with the plane of the ecliptic an angle of about seven degrees.

When Mercury in his retrograde movement plunges into the sun's rays, it sometimes happens that he is seen traversing the sun's disk under the form of a black spot. It is he no doubt; for the position, the motion, and the diameter are the same. This is what is called the *transit* of Mercury: it does not take place for us in every revolution, on account of the inclination of his orbit to the plane of the ecliptic: we can only see the planet on the sun's disk when the planet is in the point of its orbital intersection with the ecliptic, and when the line connecting its centre with that of the sun passes also through the centre of the earth. The smallness of this planet, however, its distance from the earth, and its proximity to the sun, frequently prevent us from witnessing its transits, which regularly recur after periods of six, seven, thirteen, forty-six, and 263 years. The next which will occur, will take place in the year 1861.

Physical constitution of Mercury.

Mercury is of a perfectly spherical form. Like all the planets, it borrows its light from the sun: this is proved both by its transits across the sun's disk, during which it appears as a dark spot, and by the phases it presents; which may be observed with the help of a telescope, to be like those of the moon.

By means of this instrument, it has also been discovered that one horn of its crescent is truncated; and it is this truncature that has enabled us to determine the period of its rotation, for this planet has no spots on its surface. This truncature is probably an effect of the asperities that no doubt ruffle its surface, and which in a certain position screen from our view some of the points illuminated by the sun.

It is thought that Mercury is enveloped by an extremely dense atmosphere. Its motion from point to point in space is more rapid than that of any of the other planets, because it is nearer the sun. The latter appears to it thrice as great as to us, and Newton has calculated that it transmits to it a heat seven times that of our torrid zone. But we must not conclude too hastily from thence, that the planet really sustains so highly exalted a temperature: we are not yet sufficiently acquainted with the causes that produce heat, to be at liberty to establish this inference: on the contrary, it is very possible that the sun's rays may be modified in their action by the nature of the constituent elements of the different planets.

Venus ♀.

Venus is the most beautiful of all the stars; it is for this reason she has received the name she bears. Like Mercury, she appears sometimes in the morning, sometimes in the evening, and she is called the morning or the evening star, accordingly as she is seen before the rising, or after the setting of the sun. Some days after her conjunction with the sun, she is seen first in the morning on the east of that luminary, under the form of a handsome crescent, the convexity of which is turned towards the sun. She moves westward; and as she proceeds, her motion becomes slower, and her crescent enlarges, until at last she arrives at the point where she remains stationary for a time, being then in the form of a semicircle. She then sets off again towards the east, and gradually accelerates her motion till she arrives at the sun. Some time after this she is seen in the evening east of him, quite round, but very small; she continues her course eastward, augmenting in diameter, but diminishing in roundness, till she again becomes a semicircle. Lastly, she again takes a western direction, constantly increasing in diameter, but presenting a disk having only a crescent out of a full circle, and then ends by returning to conjunction with the sun.

The distance of Venus from the earth, like that of Mercury, is very variable, as is shown by the apparent variations in their diameters. Her mean distance from the sun is seventy millions of miles: her apparent diameter varies from 17″ to 61″. Her rotation on her axis takes place in 23^h 21′ 19″, and the period of her revolution round the sun is 224^d 16^h 49′. Her orbit is inclined 3° 24′ to the ecliptic, and is always enclosed within that of the earth.

Venus, as well as Mercury, exhibits transits over the sun's disk, and like him appears then under the form of a dark spot. These phenomena are very rare, and astronomers avail themselves of them to measure her distance and that of the sun with accuracy. We have elsewhere mentioned that by means of these transits the sun's parallax has been obtained to within a tenth of a second.

Physical constitution of Venus.

When this planet is projected on the disk of the sun, she takes the form of a small round black spot: her figure is therefore spherical, and her light borrowed from the sun, as we already had reason to conclude from observing her phases.

The duration of her rotary motion has been determined, as in the case of Mercury, by observing the asperities of her surface, which, intercepting the light she reflects, give a truncated form to the horns of her crescent; the length of her day is the same as the interval elapsing between two successive appearances of the observed truncature. This planet is enveloped in an atmosphere: a German astronomer arrived at this conclusion by calculations founded on the laws of the degradation of light; and the fact is established, that her illuminated portion is larger than it should be, were it not for refraction.

Although almost as large as the earth, Venus moves with more rapidity, because she is nearer the sun. This luminary appears to her twice as large as it does to the earth, and Mercury is her morning and evening-star as she is ours.

The axis of Venus is inclined 75 degrees to her orbit, that is, 51 and a half degrees more than the earth's axis to the ecliptic The northern pole of her axis points towards the 20th degree of Aquarius in a direction from Cancer; consequently, the northern regions of Venus have summer in those signs in which we have winter, and *vice versâ.* As the greatest declination of the sun on each side of her equator amounts to 75 degrees, her tropics are 15 degrees from her poles, and her polar circles at the same distance from her equator. She has, therefore, at her equator two summers and two winters in each of her annual revolutions.

Numerous endeavours have been made to ascertain whether Mercury and Venus have satellites, but none have been discovered, and it is highly probable that these have only been given to the superior planets.

Superior Planets.

The two planets of which we have just spoken, are called *inferior* or *interior*, because, as we have already said, they are less distant than the earth from the sun: those to which we are now about to direct our attention, are called *superior* or *exterior*, in opposition to the others, because the earth is nearer than they to the sun.

Mars. ♂.

This planet comes immediately after our earth in respect of distance from the sun. It appears to move from west to east round the earth ; but its motion exhibits numerous irregularities, in consequence of its nearness to the earth, and the motion likewise of the latter. After conjunction, when it begins to separate from the sun, its course is very rapid ; but this rapidity diminishes gradually, and seems to cease altogether at about 137 degrees. The planet then takes a direct motion, which brings it in opposition with the sun; its rapidity then progressively diminishes again, and it seems to retrograde till it has passed the sun 137 degrees: its motion then becomes once more direct, till at last the planet plunges into the sun's rays.

The mean distance of Mars from the sun is 146 millions of miles. As its distance from the earth is very variable, this variation exhibits its effects in the apparent dimensions of its diameter, which is sometimes 4″, sometimes 18″. Observations of the spots on his disk show that Mars revolves on his axis in 24^h 31′ 22″. He moves in a very eccentric ellipse, which he travels over in 686^d 23^h 30′ 41″.4. His axis is inclined to the plane of his own orbit at an angle of 61° 33′, and the inclination of his orbit to the ecliptic is 1° 51′ 1″. His equatorial is to his polar diameter in the proportion of 16 to 15.

Mars undergoes great variations of distance in his course through his orbit; sometimes he appears near, sometimes far from the sun: sometimes he rises when that luminary sets, and sets when he rises: his distance too from the earth varies prodigiously, being least in opposition, and greatest in conjunction. He exhibits the phenomena of phases as well as Mercury and Venus, but not like them a truncated crescent.

Physical constitution of Mars.

When this planet is observed through a telescope, it exhibits a rounded disk, which, never appearing indented, has probably few asperities. Its phases prove that it has no light of its own. On its surface are seen spots of various tints, by the aid of which the period of its rotation has been determined. The light reflected by Mars is a dark red, owing, it is presumed, to his atmosphere, which is so deep and dense, that when he approaches any star, the latter changes colour, grows dim, and often disappears, though it be at some distance from the body of the planet.

Besides the spots, which have served for determining the period of the rotation of Mars, several astronomers have remarked that a segment of his globe towards his south pole has a lustre so superior to that of the remainder of the disk, that it seems like a segment of a larger globe. Maraldi informs us that this brilliant spot was observed sixty years ago, and that it was the most permanent of all. A part of this planet is more brilliant than the rest: the darker portion is subject to great changes, and at times disappears. A similar brilliancy has often been observed at the northern pole. These observations have been confirmed by Herschel, who examined the planet with more powerful and better-constructed instruments than had been employed before his time. According to this astronomer, the analogy between Mars and Venus is the greatest presented throughout the solar system. Both bodies have almost the same diurnal motion : the obliquities of their ecliptics present but little difference. Of all the superior planets, Mars is that whose distance from the sun differs the least from the earth's, and the length of his year does not much differ from ours, in comparison with the extreme duration of those of Jupiter, Saturn, Uranus, and Neptune. Since the globe we inhabit has its polar regions and mountains covered with snow and ice, which melt partially when they are alternately exposed to the action of the sun, it is reasonable to suppose that the same causes produce the same effects upon Mars ; that these lustrous polar spots are owing to the vivid reflection of light from those icy regions, and that the diminution of these spots, when they are exposed to the sun's rays, is caused by the influence of that luminary. The south polar spot was extremely brilliant in 1781, which might have been expected, since that pole was then issuing from a night of twelve months' duration, during all which time it had been deprived of the light of the sun: it was smaller in 1783, and diminished gradually from the 20th of May to the middle of September, when it seemed to grow stationary. At this epoch the southern pole had enjoyed eight months' summer, during which it had constantly undergone the influence of the sun's rays. It is true that, towards the close of this period, they were so oblique that they could not act very strongly upon the region in question. On the other hand, the northern pole, which, from an exposure of twelve months away from the sun, had fallen into deep obscurity, appeared of small dimensions, though it had, no doubt, increased in volume. It was not visible in 1783, on account of the position of the axis, which did not allow us to see this pole.

Another consideration adds strength to the hypothesis that the brilliant spots about the poles of Mars are caused by the presence of snow and ice; namely, that the axis of this planet being inclined at an angle of 61° 35′ to its orbit, the variations of the seasons must be in a like proportion with those of the earth; and this constancy of each parallel in preserving a similar temperature, is regarded as favourable to the formation of ice.

The sun affords to Mars rather more than half the quantity of light, or thereabouts, which he sheds on the earth; it appears strange, therefore, that this planet has no moon or satellite. This circumstance, however, may be compensated for by the depth and density of its atmosphere, which we have seen to be considerable.

The telescopic Planets.

These planets, which are situated in the solar system, between Mars and Jupiter, are discoveries of modern date. To this circumstance, combined with their small sizes and distances, it is owing that they are very little known.

The first four, described below, were discovered at the beginning of the present century. They have been called *telescopic* planets, because seen only with a powerful telescope.

The world has been greatly astonished, within the last half-dozen years, to hear of the discovery of a host of *new* asteroids, belonging evidently to the same group or family as the four known during the last fifty years. Mr. J. R. Hind, and other eminent astronomers, have reported the discovery of as many as twenty-three; the names of which are as follows:—Astræa, Hebe, Iris, Flora, Metis, Hygeia, Parthenope, Victoria, Egeria, Irene, Eunomia, Psyche, Thetis, Melpomene, Fortuna, Massilia, Calliope, Lutetia, Thalia, Phocea; and three others not yet named.

We believe that particular statements regarding the elements of any of the asteroids are chiefly conjectural: the measures of their diameters being very uncertain; and the times of their diurnal rotation, and the angles of inclination of their axes, being unknown.

Juno ⚵.

This planet, discovered by Harding, the 1st of September, 1803, is 1,320 miles in diameter, according to Schröter. It takes four years 128 days to complete its revolution round the sun, in an orbit inclined 23° 4½′ to the ecliptic: its distance from the sun is about 256 millions of miles.

Ceres ⚳.

Of the four telescopic planets, Ceres was the first discovered, by Piazzi, the 1st of January, 1801. Its diameter, 140 miles according to Herschel, but 1,320 according to Schröter, is not well known. It makes its revolution round the sun in four years and a half, in an orbit inclined 10° 37′ 25″ to the plane of the ecliptic. Its distance from the sun is about 264 millions of miles. Its appearance is that of a nebulous star, surrounded by very variable mists, which induced Herschel to suppose it possessed of an atmosphere.

Pallas ⚴.

This planet was discovered by Olbers, the 28th of March, 1802. Schröter assigns it a diameter of 1,950 miles, and Herschel one of but 140. Its extremely elongated orbit is the most oblique of all to the ecliptic, making with it an angle of 34° 37′ 30″. This orbit it describes in four years, seven months, and eleven days. Its distance from the sun is 267 millions of miles; its colour is whitish, and it appears rather indistinct, even with a powerful instrument.

Vesta ⚶.

Vesta was discovered by a pupil of Olbers, the 29th of March, 1807. It describes its orbit in three years, sixty-six days, four hours; this appears very irregular, and is inclined 7° 8′ to the ecliptic. This small planet is very little known. When observed by Herschel, with an instrument of great magnifying powers, it did not present the appearance of a disk, but seemed only like a brilliant point. It is thought to be 225 millions of miles from the sun.

Though the dimensions of these four planets be not yet thoroughly known, we may, however, assert that they are extremely small, compared with the old planets in their vicinity, and with regard to their distance from the sun. Another anomaly they present is, that they deviate considerably from the zodiac or the path of the planets. These considerations have given rise to a bold conjecture, namely, that these little planets may, possibly, be but the fragments of a single planet formerly situated between Mars and Jupiter. This opinion acquires a high degree of probability, if to the preceding grounds we add, that these planets are not round, as is indicated by the instantaneous diminution of their light when they present their angular faces, and that the intersection of their orbits, whereby they all successively pass through the same point, is strictly in accordance with what would be required by the laws of mechanics in the case in question. In fact, according to these laws, were a planet to burst violently, each of its fragments after describing a new orbit, would return and pass through the point where the explosion had taken place.

LECTURE VII.

SUPERIOR PLANETS CONTINUED—JUPITER AND HIS SATELLITES—PHYSICAL CONSTITUTION OF SATURN; HIS RING AND SATELLITES—URANUS AND HIS SATELLITES—NEPTUNE AND HIS SATELLITES.

Jupiter ♃ and his Satellites.

JUPITER is the largest of the planets, and, next to Venus, the most brilliant. It is 1,300 times the size of the earth, and it is owing to its prodigious distance from us, that it appears so small. Its movement on its axis is extremely rapid, being completed in 9h 56′. Its revolution round the sun takes place in 4332·596d, in an ellipse, making an angle of 1° 19′ with the ecliptic. The distance at which Jupiter is placed, does not allow of our seeing the phases he no doubt undergoes, like all the other planets.

Seen through the telescope, Jupiter appears accompanied by four small luminous bodies, which revolve round him, and are called his *satellites.* They are distinguished by their positions, the first being that nearest the planet. They move in orbits almost in the plane of the equator; the first in 1d 18h 27′ 35″; the second in 3d 13h 13′ 42″; the third in 7d 3h 42′ 33″; the fourth in 16d 16h 32′ 8″.

The first three move in planes diverging but very little from each other, but the fourth in one rather more so: their orbits are almost circular; no eccentricity has been detected except in those of the third and fourth; that of the latter is more particularly discernible.

The motions of the first three exhibit singular relations to each other. The mean sidereal motion of the first, added to twice that of the third, is constantly equal to three times the mean motion of the second; and the sidereal, or mean synodical longitude of the first, minus three times that of the second, plus twice that of the third, is always equal to two right angles.

Herschel, on attentively examining these satellites through the telescope, perceived that the intensity of their light exhibited periodical variations, and by calculating the periods when their faces are turned towards us, he was able to determine the duration of the rotation round their axes. He found that they always turned the same face towards Jupiter, and thus made but one complete turn on their axis during the time of their describing an entire circumference of their orbits, thus strikingly confirming their analogy with the moon. Maraldi had already established this fact with regard to the fourth satellite, by observing the returns of one spot observed on its disk.

When the satellites of Jupiter, in their revolution round him, happen to pass between him and the sun, they project, on the enlightened portion of his disk, a shadow varying with the distance and size of each of them. This then is a partial eclipse of the planet, and from it we infer that neither Jupiter nor his satellites are self-lustrous.

When, on the other hand, the satellites pass behind the planet, they are seen successively to disappear; this is the eclipse of the satellites. The first three are eclipsed at every revolution, but the fourth has an orbit so oblique, that, when in opposition to Jupiter, he escapes falling into the shadow two years in every six. We perceive, from the strange proportions we have mentioned, that, for a great number of years, at least, the first three satellites cannot be eclipsed together; for, in the simultaneous eclipses of the second and third, the first is constantly in conjunction with Jupiter, and *vice versâ.*

It has been remarked that these eclipses never take place from east to west, but on their return from west to east; hence it follows that the satellites revolve, like all the other planets of our system, from west to east.

These eclipses of Jupiter's satellites have furnished the means, as we shall see by-and-by, of determining the velocity of light. We shall also see that they are of great use to navigators for determining the longitude.

Physical constitution of Jupiter.

We have seen that Jupiter, as well as his satellites, borrows his light from the sun. Though 1,300 times larger than the earth, his density is but one-fourth of that of our planet. His form is that of a spheroid flattened at the poles: this flattening, which amounts to $\frac{1}{14}$, is the effect of the rapidity of his rotary motion, as we shall show in speaking of the earth. His axis being nearly perpendicular to the plane of his orbit, the sun is almost always in the plane of his equator, so that the variation of his seasons is almost insensible, and his days and nights are always nearly equal.

The sun appears to Jupiter five times smaller than to us, and sends him twenty-five times less heat and light; but his nights are very short, and illuminated by four brilliant moons, one, at least, of which is always shining.

Fig. 20.

When Jupiter is observed with a good telescope, a number of zones or bands are perceived, browner than the rest of his disk: they are generally parallel to the equator, but in other respects they are subject to great variations. Sometimes but one of them is seen, at others as many as eight. Sometimes they are not parallel to each other and are of variable dimensions; one of them often contracts, while that nearest to it dilates; and they seem as it were to melt into each other. The time of their duration varies: some have been seen to keep the same form for three months, and new ones have been seen to form in an hour or two. The continuity of these bands is sometimes interrupted, which gives them a lacerated appearance. The spots and bands, which were observed the 7th of

April, 1792, are represented in the annexed figure. They are considered as resting on the body of the planet, and the luminous parts as clouds carried along by the winds in different directions and with different velocities.

Saturn ♄, his Ring and Satellites.

Seen by the naked eye, Saturn presents the appearance of a nebulous star of a dull leaden lustre, and as its motion is very slow, it is hardly distinguished from a fixed star. It exhibits parallel to its equator a series of bands, like those of Jupiter, but fainter, and it was by means of them that Herschel determined the period of the planet's rotation, this it accomplishes in ten hours and a half. The flattening of its poles is one-eleventh: it moves at the distance of 915 millions of miles from the sun, in an orbit it describes in twenty-nine years, five months, fourteen days, and the inclination of which to the ecliptic is 2° 30′. This planet is 900 times larger than the earth, and the sun sends to it but the eightieth part of the light he dispenses to us.

Like Jupiter, Saturn too has his satellites, eight in number: six move almost in the plane of the equator, but the seventh diverges sensibly from it, the inclination of its orbit being about thirty degrees. It is ascertained that it makes but one turn round its axis during the period of its revolution; and, though it has not yet been proved whether or not this is the case with the others, analogy disposes us to believe it, for this equality in locomotion and rotation appears to be the law of secondary planets.

The periods of revolution of the satellites of Saturn present somewhat considerable differences.

The first completes its mean sidereal revolution in the space of $22^h\ 37'\ 23''$; the second in $1^d\ 8^h\ 53'\ 9''$; the third in $1^d\ 21^h\ 18'\ 26''$; the fourth in $2^d\ 17^h\ 44'\ 51''$; the fifth in $4^d\ 12^h\ 25'\ 11''$; the sixth in $15^d\ 22^h\ 41'\ 14''$; the seventh in $79^d\ 7^h\ 54'\ 37''$. The names of these different satellites are as follows:—Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Japetus, and Hyperion.

Saturn's satellites undergo frequent eclipses, which serve like those of Jupiter to determine longitude, but their great distance renders the observation of them more difficult.

Saturn, already so remarkable for the number of his satellites, is still more so for the ring with which he is enveloped. It is a luminous band situated in the plane of the planet's equator, forming a kind of belt to it, but separated from it by a distance equal to its breadth. It appears under the form of an ellipse more or less elongated, according to the obliquity under which it is seen, arising from the various inclinations with respect to our position assumed by Saturn in his revolution round the sun. When the ring affects the elliptic form, the extremities of its major axis are called *anses*,* and in this condition, when the obliquity is not too great, stars may be seen between it and the planet. But when its position is such that the prolongation of its plane passes through the centre of the earth, it only shows us its edge, and the angle it then subtends is so small, that it needs a very powerfully magnifying instrument to make it visible. It appears then as a luminous thread, dividing the planet's disk.

Fig. 21.

When we use powerful telescopes, we discover on the surface of the ring several black lines, which seem to constitute so many separations; but above all, two rings are conspicuous, and of these Herschel has calculated the divisions. According to this astronomer, the interior diameter of the smaller ring is 117,339 miles, and the exterior diameter of the larger 176,418; the space between the two rings 1,791 miles. Hence it would appear that between the body of Saturn and the interior diameter of the inner ring, there is a distance of 19,170 miles.

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* From the Latin word *ansæ*, handles.

By means of the spots on the ring, Herschel has determined the duration of its rotation on its axis: it is 10h 19′ 16″. This axis of rotation is perpendicular to its plane, and is the same as that of Saturn.

The duration of this rotation, which appears to be precisely that of a satellite having for its orbit the mean circumference of the ring, has enabled M. Biot to explain how the ring can sustain itself round the planet without touching it, or at least to connect this fact with the general cause that thus sustains all the satellites.

In fact, he says, we may consider each part of the ring as a small satellite of Saturn, and the ring itself as an assemblage of satellites connected together in an invariable manner. If these bodies were free and independent of each other, their velocity would vary with their distances from the centre of the planet; the nearest to the centre would move more rapidly, those further off more slowly; and if we take for a mean velocity that which answers to the mean circumference of the ring, the velocities of the other particles would differ from it, in excess or in deficiency, by an equal quantity. Now if the particles become united and attached together so as to form a solid body, a sort of compensation will take place between their motions; the more rapid will communicate a part of their speed to the slower, and these again a part of their slowness to the former, and these opposite efforts mutually balancing each other, there will remain only the mean velocity common to all the particles, which will be that of the mean circumference. These rings will sustain themselves round Saturn as the moon does round the earth, or as the arches of a bridge would do, if the centre of gravity were in the centre of the voussoirs.

This theory would subsist, even though the ring should be composed, as appears to be the case, of several concentric rings detached from each other; only it would then be necessary to apply it separately to each of them, for the duration of their several rotations would necessarily be different.

Sometimes Saturn's ring, projecting itself on the disk of the planet, hides a part of it; and sometimes again, the planet conceals with its shadow a part of the ring. It follows from this, that the ring is opaque like the planet, and that the light of both is borrowed.

Uranus ♅ and its Satellites.

This planet was till lately thought to be of all the most remote from the sun, and its orbit to embrace that of all the others. Situated at a distance of more than 1,840 millions of miles, it accomplishes its revolution in eighty-four years. The inclination of its orbit to the ecliptic is but 46′ 26″. Its time of diurnal rotation is not determined; but is supposed to be about 9½ hours.

Hardly visible to the naked eye, it presents under the telescope a bluish-white colour. Its disk is well defined. It derives from the sun only the three hundred and sixty-second part of the light that we receive.

When it was discovered, it was at first taken for a comet; but its proximity to the ecliptic showed soon that it was a planet. It had previously been regarded as a fixed star.

Herschel, who recognised it for a planet, discovered also its six satellites, which circulate round it nearly in the same plane—that is, nearly at right angles with the ecliptic; their course is consequently, in some measure, an exception to the general law of the system of motion, from west to east. Herschel suspected the planet to possess two rings, perpendicular to each other, but this curious circumstance has not yet been confirmed.

Besides the proximity of this planet to the ecliptic, it was observed to change its place relatively to the stars in its neighbourhood, and to appear enlarged under the power of the telescope. Its actual diameter is 34,500 miles; but it subtends an angle of about 4″, which never appears to vary, owing to the comparative smallness of our orbit. Herschel, the discoverer, named it *Georgium sidus*, or the Georgian star, by which name it was long known in the Nautical Almanack. Foreign astronomers called it *Herschel*, from the name of its discoverer; but the Royal Academy of Prussia called it Uranus, by which name it is now universally recognised.

The first satellite accomplishes its sidereal revolution in the space of $5^d\,21^h\,25'\,21''$; the second in $8^d\,16^h\,57'\,47''$; the third in $10^d\,23^h\,3'\,59''$; the fourth in $13^d\,10^h\,56'\,30''$; the fifth in $38^d\,1^h\,48'$; the sixth in $107^d\,16^h\,39'\,56''$. The names of four of these, whose existence is undoubted, are Ariel, Umbriel, Oberon, and Titania.

At the end of the volume is a table presenting at one view all the circumstances of the planets as to bulk, quantity of matter, density, distance, velocity, inclination, &c., compared the one with the other.

Neptune ♆ and its Satellites.

Soon after the discovery of the planet Uranus, M. Bouvard undertook to construct tables for estimating the places of Uranus at any given time, as he had done in the cases of Jupiter and Saturn. Now it was found, that, with the tables, similarly constructed, the true longitude of Uranus was soon in advance of the computed; which advance was kept up from about 1795 to 1822. Then, it began to diminish; till, at the beginning of 1831, the tabular and observed longitudes agreed. For some years after this, the planet kept on falling behind its calculated place; so that it became quite evident, that the tables then in use had failed in their application to the orbit of the planet.

Hence, at the beginning of 1822, as Herschel observes, "some extraneous cause must have come into action, which was not so before, or not in sufficient power to manifest itself by any marked effect, and that *that* cause must have ceased to act, or rather begun to reverse its action, in or about the year 1822, the reverse action being even more energetic than the direct."

In consequence of the observations thus made, the year 1846 was distinguished by the discovery of a new planet beyond the limits of Uranus, to which was eventually given the name of **Neptune.** M. Le Verrier, in France, had been long engaged in calculations concerning the position of this unseen disturbing body. In the month of September, he sent a communication to the conductors of the Berlin Observatory, pointing out in what part of the heavens the new planet should be sought for. On the night of the 23rd, it was seen by Dr. Galle, and appeared like a star of the eighth magnitude.

This planet is accompanied by one, if not two, satellites, and is supposed to be surrounded by a ring. There are probably many satellites; but the period of the one which has been proved is almost six days. It moves in an orbit inclined to the ecliptic at an angle of about 35°, and at a distance from the planet of about 232,000 miles.

The elements of the planet Neptune have not perhaps as yet been thoroughly investigated; but we may state that it revolves round the sun in an orbit inclined to the ecliptic, at an angle of about 1° 47′. The mean radius of its orbit is about 2,862,457,000 miles; or it is about 30 times as far off from the sun as the earth. This calculation does not accord with Bode's rule, page 55, which would give 388; whereas the existing exposition of the elements furnishes only 309.

The time of the diurnal rotation of Neptune, and the angle of inclination of his axis, are unknown; but he completes his circuit round the sun in about $164\frac{1}{2}$ years. His diameter amounts to about 35,000 miles. His density is about $\frac{1}{5}$ of that of the earth; and the light and heat received by him from the sun is about $\frac{1}{1000}$ part of that received by the earth. Its apparent diameter, which is subject to no sensible variation, is about 2·6″.

This planet, as we said had been the case with Uranus, had been several times notified in former years, as a fixed star. This was obviously owing to the slow motions of these planets, and particularly of the newly discovered one.

LECTURE VIII.

KEPLER'S LAWS—UNIVERSAL ATTRACTION—MASSES OF THE PLANETS.

Kepler's Laws.

In treating of the planets, we have contented ourselves with saying, that they describe round the sun elliptic curves more or less elongated, but we have not yet inquired into the means of determining these orbits, nor have we studied their nature.

The curves described by the planets all make angles greater or less with the plane of the ecliptic, consequently they all cut it in two exactly opposite points called *nodes*. The line joining these points is the *line of the nodes:* this line marks the intersection of the plane of the orbit with that of the ecliptic.

Let us now suppose a spectator placed in the sun: it will be easy for him to distinguish the precise instant of the passage of the planet at its nodes; it will be when he sees it in the line passing through the node and the centre of the sun. As for the observer situated on the earth, that is to say, out of the centre of the planetary system, he can certainly mark the instant of the passage of the nodes, but he cannot see them when they are constantly opposed to each other, because the right line joining them assumes successively various inclinations in consequence of the sun's motion; it sometimes happens, however, but very rarely, that the earth and the sun being in a line, the planet we wish to observe is also in the prolongation of the same line. The planet is then seen at the same point as the sun, its longitude can be ascertained, and several such observations will enable us to determine if the planet's node always corresponds to the same longitude seen from the sun.

The node being known, to determine the inclination we wait till the sun's longitude is the same as the planet's, and then we find the latitude of the star, whence we deduce the inclination of the plane of the orbit.

These data being obtained, to determine the nature of the curve we measure the duration of an entire revolution, which is done by watching a point, one of the nodes for instance, and reckoning the time that elapses between two successive passages of the star through this point.

When the duration of the motion has thus been obtained, nothing remains but to determine, by means of the oppositions and conjunctions, the angular motion of the planet.

When we have thus traced the orbits of the planets, we find—

1. *That the planets all move in ellipses, of which the sun occupies one of the foci.*
2. *That the motion is the more rapid the nearer the planet is to the sun, so that the radius vector always describes equal surfaces in a given time.*
3. *That the squares of the times of revolution are to each other as the cubes of the major axes of the orbits.*

These are Kepler's three laws: they are the foundation of all Astronomy. We shall presently see how they involve in them the general law of attraction. These interesting laws, tested for every planet, have been found so perfectly exact, that we do not hesitate to infer the distances of the planets from the sun from the duration of their sidereal revolutions: and it is obvious that this mode of estimating distances possesses considerable advantages in point of exactness, for it is always easy to determine precisely the return of each planet to a point in the heavens, whilst it is very difficult to calculate directly its distance from the sun.

Universal Attraction.

The announcement of Kepler's laws, rendering so great a service to Astronomy by discovering the marvellous relations between the celestial motions, could not fail of exciting inquiry as to the causes that governed these movements. This discovery was reserved for the genius of Newton. We shall not repeat how he was conducted to it by reflecting on the cause which had made an apple fall at his feet—a cause whose operation he conceived the brilliant idea of extending to the stars; neither shall we enter into the intricate and laboriously calculated details, by which he succeeded in establishing this general cause. We shall confine ourselves to an exposition of the consequences he deduced from Kepler's laws.

From the law that the areas described by the radius vector are proportional to the times, Newton draws this conclusion, supported by calculation, *that the force acting on the planets is directed towards the centre of the sun.*

From the law that the orbits of the planets are ellipses, of which the sun occupies one of the foci, he concludes, *that the force acting on the planets is in the inverse ratio of the square of the distance of their centres from that of the sun.*

Lastly, from the law that the squares of the times of revolution are to each other as the cubes of the major axes of the orbits, he draws this consequence, that *the force is proportionate to the mass.*

From all these results it follows that the sun is the centre of an attractive power, which acts in accordance with the laws we have just stated.

Newton, who, setting out from the attraction exercised by the earth over the bodies on its surface, extended the operation of the same principle to the moon, was led to conclude from analogy, that, since the other planets also retain their satellites in their orbits, they must possess like the earth an attractive force, and that it can only be a force of the same nature that gives the sun the power to make all the other planets of his system circulate round him.

Thus all the bodies that revolve round the sun are like him endowed with the power of attraction; and, if we push the analogy further, we arrive at this general result now adopted in physics, and which might have been anticipated from the sphericity of the heavenly bodies, namely, that all the molecules of matter mutually attract each other with a force directly proportioned to their mass, and inversely to the square of their distances.

But, as the force of attraction, if it existed alone, could only tend to unite all the globes in nature into a single mass, Newton supposed that the heavenly bodies received a primitive impulse in a direct line, and that from the combination of these two forces arose the curvilinear orbit.

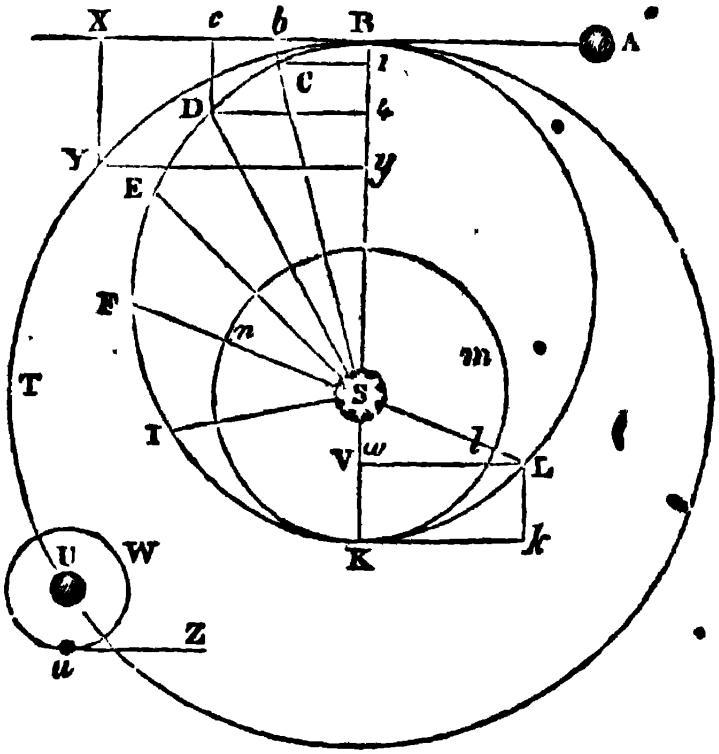

Fig. 22.

To illustrate this, suppose the body A is projected in the direction of the right line ABX into free space, where it meets no resistance to weaken the impulse it has received, it will continue to move on for ever with the same velocity and in the same direction. But if, on arriving at B, it is attracted by S, with a sufficient force perpendicular to its line of motion, it will quit the straight line ABX, and will describe round S the circle BYTU. In order that the body should thus describe a circle, it is necessary that the projectile force should be equal to that which it would have acquired from gravity alone in falling through the semi-radius of the circle. Thus, that the body on arriving at B should describe the circle BYTU, it is necessary it should be attracted by S so as to fall from B to Y (equal to half the radius BS) in the time it would take to go from B to X, by the sole force of the projectile impulse. A may represent a planet, and S the sun.

But if, whilst the projectile force is carrying the planet from B to *b*, the sun's attraction should make it fall from B to 1, the force of gravitation would be proportionally greater than in the former case, and the planet would describe the curve BC. On the planet's arriving at C, the attractive force, augmenting inversely as the squares of the distances, would be greater than at B, and would make the planet fall still more, so as to describe the arcs BC, CD, DE, EF, in equal times; the planet would therefore move much more rapidly than before; accordingly it would acquire a greater tendency to fly off at the tangent K*k*, or in other words, a greater projectile force, which would be sufficiently powerful to overcome the force of attraction, and to prevent the planet falling upon the sun, or even from moving in the circle K*lmn*. The planet would therefore increase its distance, following the course of the curve KLB, but its velocity would gradually decrease from K to B, as it had augmented from B to K, because the attraction of the sun would now operate in an opposite direction. Having come back to B, after having lost from K to B the excess of velocity it has acquired from B to K, it would obey the same forces and describe the same curve.

A double projectile force balances a quadruple attractive force. Let us suppose for instance, that the planet at B has towards X double the impulse it had before; that is to say, that it passes from B to *c* in the time it before took to move from B to *b*: in that case it will require four times as great a force of gravity to retain it in its orbit; that is to say, a force capable of making it fall from B to 4, in the time the projectile force would carry it from B to *c*; otherwise it could not describe the curve BD as shown in the figure.

As the planets approach towards and recede from the sun at every revolution, some difficulty may be felt in conceiving how in the first case they do not approach more and more, till they come in contact with him; and in the second case how it is they do not recede from him never to return: but this difficulty vanishes when we study the action of these forces, and their relative intensity in the cases in question. The planet, we have said, impelled by a projectile force which would carry it from B to *b* in the time the sun would make it fall from B to 1, and subjected to the action of these two forces, describes the curve BC. But when the planet arrives at K, how will these two forces act? KS being equal to the half of BS, the planet will be twice as near the sun; the action of gravity will therefore be four times as great, according to the principle already laid down: consequently it will tend to make the planet fall from K to V in the same time as it tended to make it fall from B to 1: but the projectile force tends to carry the planet in the same time from K to *k*, a distance equal to twice B*b*, as the figure shows; this projectile force is therefore double that which it had at B. Now we have already said that a double projectile force always balances a quadruple attractive force: the equilibrium of the two forces will therefore not be broken, and the planet will continue its course from K to L, in the direction resulting from the operation of the two forces. When arrived again at B, it will again be submitted to the two forces that made it describe its orbit the first time; and as these forces will act with the same intensity as before, it will go on indefinitely describing the same curve.

Such is the grand principle of universal attraction. It is so exact, that no perturbation, no deviation, however slight, takes place, for which it does not account with the most rigid accuracy. Astronomers put such implicit faith in it, that, when their observations do not coincide with the results of their calculations, they are more disposed to believe that the error arises from the neglect of some circumstance of the case, than to question the validity of the doctrine of attraction; and, in point of fact, they always become aware at last of the cause of the error.

Masses of the Planets.

To the principle of attraction, we are also indebted for the means of arriving at a knowledge of the mass and density of the sun and the planets, of which an account will be found in the table at the end of this volume. Since the velocity of satellites in their orbits depends on the attractive force of the planet they revolve round, their masses may be inferred from their velocities. If the planet has no satellite, its mass is determined by the perturbation it produces.

The mass and the volume once known, the density may be found at once by dividing the former by the latter.

Cavendish determined the mass of our globe by another method, but one still founded on the principle of attraction. He took a very slender thread not twisted, at the extremity of which a needle was suspended, so as to be sensitive to the slightest attraction. Near this needle he placed a ball of lead, which by its attraction caused the needle to perform oscillations, the duration of which he observed. Then comparing these oscillations with those of the pendulum resulting from terrestrial gravitation, he calculated the relative force of the leaden sphere's attraction to that of gravity, and thus found the proportion of the mass of the leaden ball to that of the earth.

We shall see by-and-by, when we come to speak of the earth, that attraction has furnished the means of ascertaining the earth's dimensions with an accuracy in vain to be hoped for from direct measurements.

LECTURE IX.

THE EARTH, FIGURE OF—DIMENSIONS—MOTIONS, DIURNAL AND ANNUAL.

THE reason why, in our review of the planets, we have not spoken of the earth in its order of place, is, that, in order to treat of it fully, we wished first to be in possession of some indispensable preliminary notions.

We shall speak successively of the figure, the dimensions, and the motions of the earth.

Figure of the Earth.

Deceived by an illusion of the senses, men for a long while regarded the earth as a boundless plain, till observation gradually removed this error. It was remarked in the flat countries of the East, on approaching an elevated and distant object, that at first only the summit was seen, afterwards the less lofty points, and finally the base. This phenomenon could not be the result of local accidents, of special circumstances, for the same thing was observed in all directions; and it was the more strikingly so, in proportion as the atmosphere was purer. Nay, it was observed at sea, and here it was still more conclusive, there being no inequalities or obstacles in this situation; here all is level, and the surface of the sea must necessarily accord with the figure of the globe. Every one knows, in fact, that as often as a vessel recedes from the shore, its lower parts disappear first, then its more elevated parts successively from below upwards, and lastly the tops of the masts: mariners arriving towards port discover at first only the tops of the loftiest objects, and see the lower parts only by degrees, as they approach nearer. Subsequently, the convexity of the globe has been superabundantly demonstrated, whether by the voyages of enterprising mariners, who, after sailing round the globe, have returned to the point whence they set out by a route opposite to that on which they had started; or by astronomical observations, such as the circular form of the shadow cast by the earth on the moon's disk when the latter is eclipsed; or, finally, by operations serving to determine the dimensions of the earth, as also the direction of the plumb-line at various stations. The earth, therefore, is nearly spherical, we say *nearly*, for we shall presently see that its figure is that of a sphere, flattened at the poles and dilated at the equator. We arrive at these facts in our endeavours to determine its dimensions, and we shall see by-and-by that this form is a necessary effect of its rotation on its axis.

Dimensions of the Earth.

Since the earth has sensibly the form of a sphere, if we knew the length of one of its degrees, by multiplying it by 360 we should obtain the measure of the circumference, and consequently the diameter, the surface, and the volume of the earth.

Our task, therefore, is reduced to finding the length of a terrestrial degree. Now, to arrive at this practically, the following is the method pursued :—A space is selected on the earth, such that the perpendiculars determined by the plumb-line at each extremity of this space correspond to two stars separated from each other by one degree, and thus a terrestrial degree is obtained. As it may be supposed, there is no reason why a space greater or less than a degree might not be selected, from which the exact measure of a degree might always be deduced by a simple proportion. The remainder of the operation consists in measuring the base thus chosen, and this is done with incredible precision by trigonometrical methods, which we cannot here elucidate.

This practical determination of the terrestrial degree has confirmed the flattening of the earth at the poles, and its dilation at the equator. In fact, the degree, or the space which it is necessary to go over between two verticals to have a degree, is not the same in all latitudes: it is longer the more we approach the poles, and it is at its minimum at the equator; which indicates very plainly a flattening at the poles, and not an elongation, as had at first been supposed by a strange mistake.

The amount of this flattening, deduced from operations on the surface, is 1-306th; that is to say, the polar diameter is shorter than the equatorial by 1-306th part: the projecting ring at the equator is about thirteen miles thick: that is, the polar diameter is shorter than the equatorial by about 26 miles. These measures are obtained mathematically from the moon's motion, with much more precision than they can be determined on the ground

Gravitation enables us also to deduce them from the oscillations of the pendulum, which vary at different points of the globe, according to the force of gravity. The following are the exact dimensions of the earth :—

	Miles.
Semi-diameter of the equator	3989
„ at the pole	3975
„ taken at 45 degrees	3981
Flattening	13
Length of one degree of the meridian, taken at the mid-space between the pole and the equator	69
Fourth of the meridian of Paris	6256

The degree of the art of the meridian, of which we have here given the measurement, was taken in the middle of the space separating the pole from the equator. Moreover, in this account of the dimensions of the earth, we have made no mention of the inequalities on its surface; because, in point of fact, the highest mountain may be regarded as insensible in comparison with its volume; and the surface of the earth, notwithstanding the asperities it presents, may, relatively speaking, be considered as infinitely smoother than the rind of an orange.

The Earth's Motion.

The sphericity of the earth being established, and its dimensions known, we shall next proceed to its motion.

We shall first show that it turns upon itself, and then that it has besides a motion that carries it from point to point in space.

Diurnal Rotation of the Earth.

The whole celestial sphere appears to us to turn round the earth in twenty-four hours: is this spectacle real, or is it but an illusion?

In the first place, if we compare the earth, we shall not say merely with the globes of our system, but with the infinity of stars which, as we have seen, are nothing else than suns at least as large as ours, and probably centres of as many planetary systems, we must own that it is but an imperceptible point when contrasted with these enormous masses; and it will, no doubt, appear monstrous, that an atom should be the centre round which circulate so many immense globes. Our amazement will be vastly enhanced, if we think of the incredible velocity with which these bodies must move to describe in such brief times incommensurable circles; and as this velocity must augment with the distance, it will be necessary to admit that the earth attracts all the stars with a force, the greater, the further they are from it; a supposition which is absurd.

We must, therefore, abandon a notion which would lead to such conclusions as these, and put the question to ourselves, whether this apparent revolution of the heavens may not be the effect of an illusion of our senses. Thus we shall be led to suppose the movement of the earth; and this supposition being admitted, the phenomena will be explained logically and easily.

In reality, accompanying the earth in its rotation, we seem to ourselves to remain stationary, whilst the stars appear to us to move in the direction opposite to that we are following. In the same way, when seated in a carriage, or in a vessel at sea, we fancy we see objects removing from us with the more speed in proportion as they are nearer to us: the illusion is in this case the stronger, the greater the rapidity of the motion ; and as the crew of the vessel do not feel the motion that carries it along, so we are insensible to that of the earth, moving as it does with much more rapidity, and never encountering obstacle or resistance.

The rotary movement of the earth, thus rendered extremely probable by the natural and easy explanation it affords of the phenomena, and by the evident absurdity of the opposite opinion, it now remains that we prove it directly.

It has been asserted that if the earth turned, a body thrown up into the air ought to fall backwards ; that a stone let fall from the top of a tower, on the west side, ought not to fall at the foot of the building, because the earth had moved during the time of the fall. This is an error : experiments have shown that a projected body partakes the motion of the projector. Thus a person on board ship throws a body up into the air and catches it again with facility, and therefore he thinks he throws it up vertically ; whereas, seen from the shore, the body appears thrown obliquely upwards and forwards. Every one knows that a stone dropped from the mast of a vessel in full sail falls at the foot of the mast, just as it would do if the vessel were at rest ; and that a bottle of water inverted and suspended from the ceiling of the cabin leaks out drop by drop, and fills another placed exactly underneath, though the vessel sails several feet in the time each drop takes to fall.

But the case is still stronger, and we can even derive from it a mathematical proof of the earth's rotation. Of two bodies describing in the same time two circumferences at unequal distances from the axis of rotation, that which describes the more distant, and consequently greater circumference, must move with more rapidity than the other. Let us suppose, then, that a body be set at liberty from the top of a high tower. As the top of the tower, describing a greater curve than the base, since it is more distant than it from the axis of rotation, possesses a more rapid motion, it will communicate this rapidity to the body let fall, and this body will not take the direction of a plumb line, but will deviate from it towards the east. This has been confirmed in the most satisfactory manner by experiment.

Another proof of the earth's rotation has been derived from the transmission of light. Before examining it, we must premise that light does not move instantaneously, but takes a certain time to pass through space.

Galileo sought to solve this problem experimentally: he had a lantern constructed with a moveable shade, which could be dropped over it, so as instantaneously to intercept the light. With a lantern of this kind in his hand he ascended to the top of a mountain, whilst another person with a similar lantern stood upon an adjacent summit. Galileo had desired this person to drop the screen over his lantern the instant he lost sight of the light from that which he himself held. He supposed that, if light moved progressively, some time would elapse between the instant when he dropped his own screen and that in which he should see the light of the other lantern disappear. But he was deceived; the two lights disappeared simultaneously, whence he concluded that light is propagated instantaneously. We shall see that this erroneous conclusion was the result of his not having experimented on a sufficiently large scale.

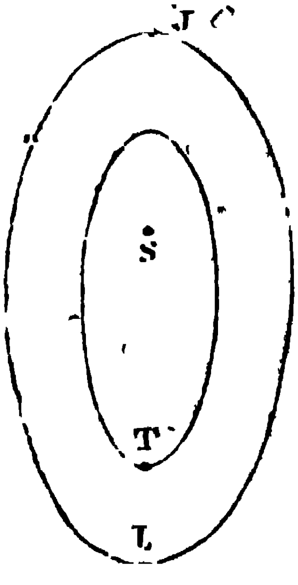

Fig. 23.

Let S be the sun, T the earth, J Jupiter at the moment of opposition, and 'J at the moment of conjunction. If we observe two immersions of one of Jupiter's satellites, the one at opposition, the other at conjunction; the time elapsing between these two immersions will amount to 16′ 26′. Now this difference can only result from the time necessary for the immersions to become visible, that is, from the time necessary for the light to arrive from J and 'J to T; or, in other words, 16′ 26″ is the time required by light to traverse the great diameter of the terrestrial orbit, whose length is one hundred and ninety-one millions of miles. Light moves, therefore, with a speed of about one hundred and ninety-two thousand miles per second.*

The progressive transmission of light being thus established, let us deduce from it our demonstration of the earth's rotation.

If the earth is immoveable, we ought not to see the stars the moment they arrive at the horizon or at the meridian, but only after the time required for the rays they emit to reach us.

If, on the contrary, the earth turns, we ought to see the stars the moment they arrive either at the horizon or at the meridian ; for in consequence of the rotary motion, the eye will fall into the line of the rays which had set out some time before from the stars, and which now arrive at the points of space traversed by our horizon.

Now we do see the stars the instant of their arrival. The proof of this is, that the culminations of Mars, for instance, would be more or less advanced or retarded according as that planet approached or receded from us, if we did not see it the moment it arrived at the meridian ; but no appearance of the kind is noticed : the earth, therefore, must turn.

The earth being about 25,000 miles in circumference, the different points of the equator describe in twenty-four hours a circle of the same dimensions, that is, about 500 yards per second. It is the speed of a cannon-ball.

Since the earth turns, it is possessed, like all other bodies subjected to a similar movement, of a centrifugal force, the intensity of which appears, both from experiment and calculation, to be in proportion to the squares of the velocities : hence, the centrifugal force is at its maximum at the equator, and is nothing at the poles. The force of gravity will therefore be less at the equator than at the poles; and this is demonstrated by the difference in the vibrations of the pendulum at these two stations. But it must not be forgotten that this difference does not depend solely on the action of the centrifugal force, for we have seen that the distance from the centre is greater at the equator than at the poles, and we know that gravity acts inversely as the squares of the distances.

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* Yet, notwithstanding this astonishing velocity, it is computed that light takes above a year in coming from the nearest of the fixed stars to the earth ; that the light of many telescopic stars may have been many hundred years in reaching us ; and, even according to Herschel, the light of some of the nebulæ just perceptible in his forty-feet telescope, has been above a million of years on its passage. —TRANS.

We are now prepared to account for the reason why the poles are flattened, whilst the equator is dilated.

The earth, like all the planets, must primitively have been fluid : this at least is an opinion which both theory and observation unite in confirming, and which is generally admitted in the present day. This being premised, let us give the earth its rotary motion round AB. The molecules situated in the canal AB, that is to say, in the line of the poles, are not actuated by any centrifugal force, and, consequently, lose nothing of their weight : the molecules, on the contrary, that fill the canal BC, are subjected to the action of the centrifugal force, which, in some degree, neutralizes attraction; they are, therefore, proportionally lighter : a greater quantity of them will therefore be necessary to maintain the equilibrium.

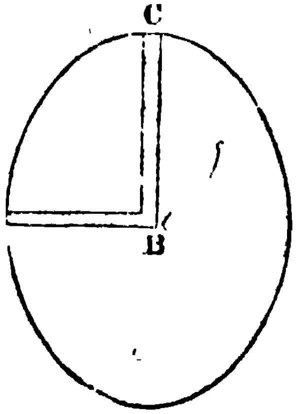

Fig. 24.

It is easy to devise experiments, showing that the velocity of rotation produces a flattened spheroid like that of the earth. Take two strips of pasteboard or other flexible material, bend them into circles and mount them upon an axis, so that they may turn with it. Make them turn slowly by means of a winch on the end of the axis, they will not undergo any change of form ; but if you give them a rapid motion, their poles sink, and the circles bulge out laterally.

Annual Motion of the Earth.

We have seen that the earth turns on its axis in 24 hours, and that the apparent revolution of the sphere is only an illusion of our senses. We have now to inquire whether the annual revolution of the sun is real, or whether this too is not an appearance caused by the earth's locomotion, for we have learned to distrust the evidence of our senses.

But first let us describe the motion of the sun. If we every day observe that body, we find that it advances every 24 hours about one degree towards the east. Now one degree corresponds to four minutes of time; the sun, therefore, daily arrives four minutes later in the plane of the meridian, so that at the end of 90 days, he will arrive six hours later than the star with which he originally arrived in company. After 180 days they will both be in the plane of the meridian at the same time, but the one will be in the superior meridian, the other in the inferior. Lastly, after 365 days and a quarter they will both meet in the meridian at the same time. The line described by the sun in the course of this movement is the ecliptic, the plane of which is inclined to the equator 23° 28′. The most elevated points of the ecliptic are called *solstices*, because the sun seems to stop in them; and the *equinoxes*, that is, the periods at which the days are equal to the nights, take place when the sun is on the plane of the equator, that is, twice a year.

Such is the course the sun appears to take in the space of a year: but is this movement real? Is it not rather the earth that traverses the ecliptic, and gives rise to the appearances we notice?

And, firstly, if we judge by analogy, we shall find it much more natural to admit that the earth, which wants only the motion of revolution to take its place amongst the class of planets, is really endowed with such a motion, than to imagine that the sun circulates round the earth with all his train of planets, in defiance of the laws of attraction. But the extreme probability of the earth's revolution is converted into the highest degree of certainty, when we derive from observation of the phenomena which this theory so naturally explains, demonstrations that remove every trace of doubt.

How is it possible indeed, upon the supposition of the earth's being stationary, to account for the phenomena of the stations and retrogradations of the planets? And what can be more natural than the explanation of these by the contrary hypothesis?

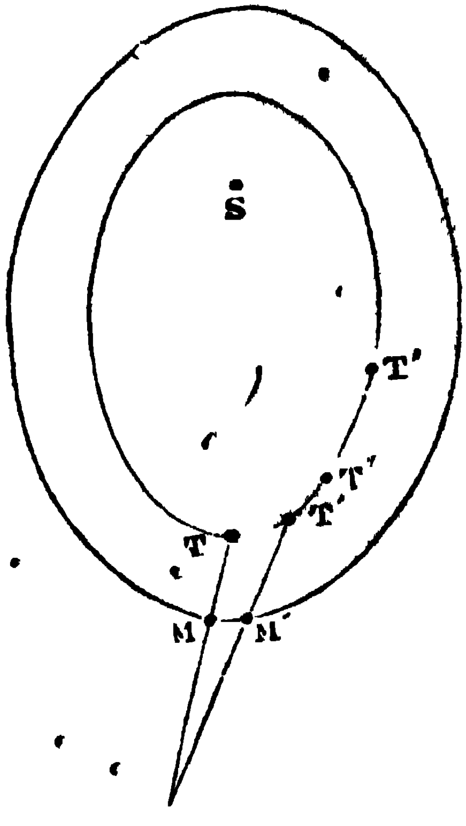

Fig. 25.

We have seen, in speaking of the planets, that these bodies appear to move sometimes from west to east, sometimes from east to west, and sometimes to remain stationary. Such is the phenomenon. Now let us suppose the earth moves along the ecliptic, and let us see what follows. Let S be the Sun, T the Earth, and M Mars, for instance. The Earth moving more rapidly than Mars, will be at T′ when that planet has only reached to M′. Mars will, therefore, in consequence of the illusion we have spoken of, appear to have retrograded towards M. But, when the earth arrives at T″, the line it will have pursued, being inclined with relation to that traced by Mars, will not effect a greater parallel length than the latter. Mars will then appear stationary. Lastly, when the earth comes to T‴, the line it describes inclining still more, Mars will appear to advance.

Such is, according to the hypothesis of the earth's motion, the natural and easy explanation of the phenomena of stations and retrogradations: it would be in vain to seek it from any other system.

Bradley, in endeavouring to determine the annual parallax of the fixed stars, discovered that they are not motionless; but that, during the time the earth takes to traverse her orbit, they appear, such of them as are in the plane of this orbit, to describe right lines—such as are in a plane perpendicular to this orbit, to describe circles—and those in intermediate planes, ellipses more or less elongated, according as they more or less approach one or other of these positions. This is the phenomenon of the *aberration of light*; from it we shall derive a new demonstration of the earth's locomotion.

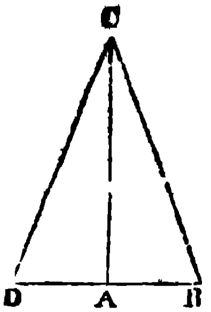

Fig. 26.

Let us remember that light requires a certain time to reach us from the stars. This being premised, let CA be a ray of light falling perpendicularly on the line BD. If the eye is at rest in A, it will see the object in the direction AC, whether the light is propagated instantly or by successive motion: but if the eye is in motion from B to A, and if light moves with a velocity which is to that with which the eye moves as CA to BA, it will pass from C to A, while the eye moves from B to A. Now each particle of light that makes the eye discern the object, is at C when the eye is at B: let us, therefore, join the two points, B and C, and suppose that the line CB is a tube, inclined to the line BD, and of such a diameter that it can only admit one particle of light. It is evident the particle of light at C, which will render the object visible to the eye when it arrives at A, will pass through the tube BC, which accompanies the eye in its movement, preserving its inclination: but since the particle of light has arrived at the eye through the tube BC, the eye will see the object in the direction of this tube. If, instead of supposing the tube extremely small, we enlarge its axis, the particle of light will still pass along this axis, if it is properly inclined. In the same way, if the eye moves from D to A, the tube CD must be inclined in the contrary direction.

It follows from this, that, if the earth moves, we do not see the stars in their real position, but a little in advance of it; and the difference between their real and their apparent position is to the sine of their visible inclination to the plane of the ecliptic, as the velocity of the earth is to that of light.*

We can now understand how the earth's motion being admitted, it follows that the fixed stars must present the phenomenon observed by Bradley; and the explanation we have just given of this phenomenon, otherwise inexplicable, constitutes the most convincing proof of the revolutionary movement of our globe.

The earth is, therefore, no longer for us the motionless centre, round which the whole universe gravitates: it is but a small planet of the solar system, obeying, like all the others, the laws of gravity. Its distance from the sun is 95,000,000 miles in round numbers: its annual revolution occupies 365^d 5^h 48′ 49″; this is called its *tropical* year. but the time it takes to accomplish its annual revolution, reckoning from a fixed star till it returns to it, is 365^d 6^h 9′ 12″: this is called its *sidereal* year. The rotation of the earth on its axis takes place in 24 hours, the length of the natural day. Its diameter is 7,964 miles. A point in the equator traverses, by reason of the rotation, about 500 yards per second; and though the earth moves in the ecliptic with a speed of 19½ miles per second, its motion is less rapid almost by one half than that of Mercury. The diameter of the earth's orbit is about 191 millions of miles. We shall not dwell longer on these details, which are fully set forth in the tables.

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* If the motion be from B to A, the star will be seen by the observer at A to the left of C, and distant from that point by a quantity proportional to BA, since the telescope at A must be placed parallel to BC. Now BA represents also by hypothesis the measure of the earth's velocity, and CA, which represents the velocity of light, is also in this case the sine of the star's visible inclination to the ecliptic. For the meaning of the word *sine* see the end of the volume.—TRANS.

LECTURE X.

THE MOON AND THE EARTH, INEQUALITIES OF.

SINCE all bodies mutually attract each other, in obedience to the laws we have already recognized, the globes of our system must mutually counteract each other in their course, and undergo a variety of perturbations. This actually occurs, and herein lies the peculiar triumph of the theory of attraction. There is not one of these derangements or perturbations, however exceedingly minute it may be, of which it does not give the most rigid computation.

The irregularities occurring in the motions of the planets and their satellites have received the name of *inequalities*. There are *secular* and *periodical inequalities.* It is not meant by this classification to infer that the former are not also periodical, but that they recur with extreme slowness, whilst the others are accomplished in a shorter space of time.

These derangements are limited: there are certain bounds they cannot pass. Thus, the curves described may be more or less irregular, may more or less approach towards or recede from the circular form, but the mean distance from the sun will never vary: the inclination of the axis to the orbit may undergo some variations, but they will never exceed certain limits.

We do not propose to speak here of any but the more remarkable inequalities of the moon and of the earth.

Inequalities of the Moon and of the Earth.

When the moon is in conjunction, that is, when in the course of her revolution she becomes situated between the sun and the earth, she is nearer the former body than in the opposite position; and the sun's attraction then acting with more intensity, the moon's distance from the earth becomes augmented. When, on the contrary, the moon is in opposition, that is to say, when the earth is between it and the sun, the latter, acting more strongly on the earth, causes it in its turn to recede from its satellite. At the quadratures the sun's action leaves the earth's to predominate. The immediate effect of these derangments is to influence the velocity of the moon's motion ; thus, it is remarked, the velocity diminishes from conjunction up to the first quadrature, and becomes accelerated from quadrature to opposition : the velocity then diminishes up to the second quadrature ; and then augments again up to conjunction. These inequalities are called *variations.*

As the moon accompanies the earth in its motion round the sun, and as the earth in the course of its revolution assumes a greater or less distance from that luminary, it is plain that these variations in distance will modify the phenomenon we have just described. This new species of inequality is named the *annual equation.*

We have already said, in treating of the moon, that its nodes move on the ecliptic from east to west, and pass through 19°·3286 yearly, thus making an entire revolution in about eighteen years, seven months, and a half, or more exactly in 6788 54019 days. This motion of the nodes of the moon's orbit, and the variations of its inclination to the ecliptic, are owing to the action of the sun. In fact, when the moon in her revolution round the earth approaches the plane of the ecliptic, the attraction of the sun makes it descend, and thus hastens the moment when it will cut the plane of the ecliptic. Hence the *retrograde motion of the nodes,* and the change of the orbit's inclination to the ecliptic.

The attraction exercised by the earth upon the moon, varies according as the latter is in apogee or in perigee, and accordingly allows more or less influence to the sun's attraction. Hence arise elongations or contractions of the moon's orbit, irregularities which are called *evections.*

But the most remarkable of these inequalities is *the precession of the equinoxes.* The sun does not every year cut the equator in the same point. If on a certain day he cuts the equator at a certain point, on the same day in the next year he cuts it at another point situated 50″·103 west of the former, and thus arrives at the equinox 20′ 23″ before having completed his revolution in the heavens, or passed from one fixed star to another. Thus the tropical year, or the true year of the seasons, is shorter than the sidereal year. The precession of the equinoxes results from the solar attraction exercised with greater intensity upon the meniscus of the equator, and tending to make it fall into the plane of the ecliptic, from which it is kept off and maintained in its inclination by the motion of rotation. Retrograding every year 50″·103 to the west, the equinoxes make a complete revolution in 25,868 years. Thus the first point of Aries ♈, which formerly corresponded to the vernal equinox, is now thirty degrees more to the west, though by a convention amongst astronomers, it always answers to the equinox.

The retrograde motion of the equinoctial points makes the axis of the earth describe, by means of a conical movement, a small circle, the diameter of which is equal to twice its inclination to the ecliptic, that is to say, 46° 56′. Let N Z S V be the earth : its axis is prolonged to the stars, and ends in A, the actual north pole of the heavens, which is vertical to N, the north pole of the earth ; let E O Q be the equator, T Z the tropic of Cancer, and V R that of Capricorn, V O Z the ecliptic, and B O X its axis, which should be considered as immoveable. because. the ecliptic always passes through the same stars. But as the equinoctial points retrograde in this plane, the axis of the earth S O N is in motion upon the centre of the earth O, so as to describe the double cone N O n and S O s, round that of the ecliptic B O X in the same time as the equinoctial points travel round this plane, that is to say, in 25,868 years ; and in this long interval, the north pole of the earth's axis describes the circle A B C D A in the starry heavens round the pole of the ecliptic, which rests motionless in the centre of the circle. The axis of the earth being inclined 23° 28′ to that of the ecliptic, the circle A B C D A described by the north pole of the earth's axis produced to A is 46° 56′, or double the inclination of the earth's axis. Consequently, the point A, which is at present the north pole of the heavens, and near a star of the second magnitude at the end of the tail of Ursa Minor, or the Lesser Bear, must be quitted by the axis of our globe, which retrograding one degree in seventy-one years and two-thirds, will point directly towards the star at B in 6,467 years, and in double that time, or 12,934 years, directly towards the star or point C, which will then be the north pole of the heavens. The actual position of the equator EOQ will be changed to *e*O*q*; the tropic of Cancer TZ into V*z*, and that of Capricorn VR into *v*Z; and the sun, in the part of the heavens where it is now in the tropic of Cancer, and makes the longest days and the shortest nights in the northern hemisphere, will then be in the terrestrial tropic of Capricorn, where it will produce to the northern hemisphere the longest nights and the shortest days. This effect will not be brought about until the completion of 12,934 years, the period necessary for the revolution of the point A to C, which is one-half of the entire circle A B C D A.

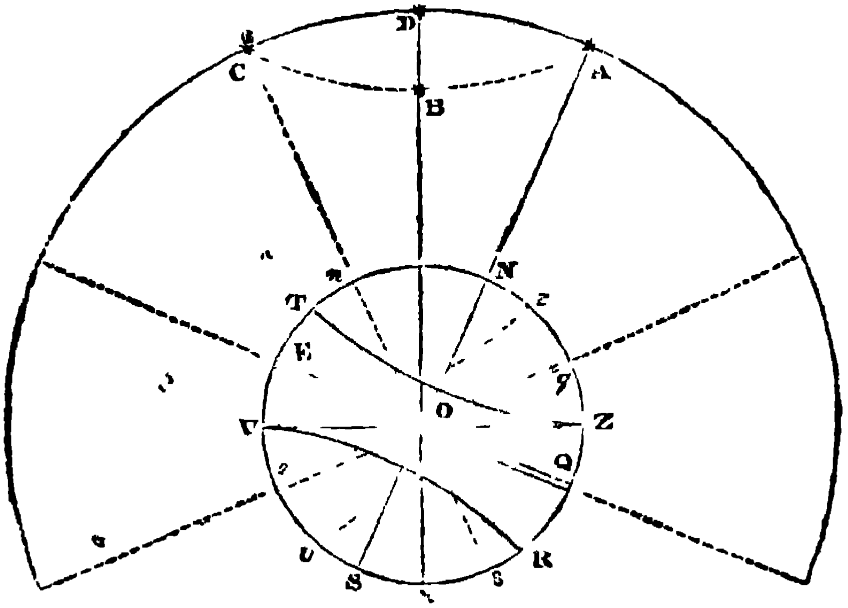

Fig. 27.

Bradley had already discovered the aberration of light, and was making new observations to confirm it, when he perceived that the axis of the earth was sometimes more, sometimes less inclined to the ecliptic, causing similar variations in the planes of the equator and the ecliptic, and that it described round the mean pole, taken as a centre, a small ellipse, the major axis of which subtends an arc of the celestial sphere of 20″·153, and the minor axis 15″·001. This ellipsis is described in the same time as the cycle of the moon, namely, in about eighteen years, seven months. The period of this *mutation* being precisely the same as that of the motion of the nodes, the two phenomena must necessarily be connected with each other. It is, in fact, the attraction of the moon that produces the phenomenon of mutation, by acting more strongly on the equatorial regions than on the poles.

Finally, besides the two inequalities we have just pointed out in the earth's motions, and which are the principal ones to which this planet is subject, we shall notice another rather important one, resulting from the combined influences of the planetary attractions: this is the gradual motion of the plane of the ecliptic through the heavens, and the secular diminution of its inclination to the equator, by a quantity equal, or nearly so, to about 48″ per century.

This change in the obliquity of the equator to the ecliptic is confirmed by the observations of ancient astronomers, and by calculation. We can convince ourselves of it by comparing the actual situation of the stars with respect to the ecliptic, to that which they occupied in the earliest times. Thus we find that those which, according to the testimony of the ancients, were situated north of the ecliptic near the summer solstice, are now more advanced towards the north, and have receded from this plane; that those which were south of the ecliptic near the summer solstice, have approached this plane; and that some have passed into it, and even beyond it, on their course northward. The contrary changes take place near the winter solstice.

M. Laplace, however, has demonstrated that this diminution in the obliquity of the ecliptic, is not of a nature to go on always augmenting, but that a period must come when this movement will begin to slacken, and then cease entirely, after which it will begin again in the opposite direction. In this way a balancing motion will take place, which can never exceed 1° 21′, to produce which effect, the term of 10,125 years will be required.

LECTURE XI.

COMETS, PHYSICAL CONSTITUTION OF—THEIR COLLISION WITH THE EARTH.

We have now to consider a numerous class of bodies, which have been the subjects of the most varied opinions: these are comets, those stars whose appearance has always struck mankind with astonishment or terror.

Let us premise a few definitions.

The word comet, according to its etymology, signifies a *hairy star*.

The *nucleus* of a comet is the central point, which is more or less lustrous. The nebulous light surrounding the nucleus, is called in French the *chevelure*, or the hair.

The luminous trains by which most comets are accompanied, were formerly called *beards* or *tails*, accordingly as they preceded or followed the comet in its line of march. At present they are called *tails*, whatever be their position.

Lastly, the nucleus and the chevelure together, constitute the *head of the comet*.

Astronomers of the present day no longer reckon amongst the essential distinctive characteristics of comets the nebulosity accompanying them. To constitute a star a comet, in their estimation, it is enough that *it possess a motion of its own, and describe an ellipse of such an eccentricity, that it cease to be visible during a part of its revolution.*

The simultaneous observations daily made on parts of the globe very remote from each other, and the participation of the comets in the general revolution of the sphere, put it beyond question that the comets are not, as was anciently supposed, meteors engendered in the atmosphere, but permanent bodies, veritable stars.

It was long imagined that comets did not follow any regular path, that they were not subject to the laws that rule the other stars, and that they wandered from system to system through the immensity of space. But since Kepler's discoveries, it has been sought to ascertain whether or not these stars were excepted from his laws, and attempts have been made to determine their orbits. For this, all that was necessary was, as we have seen, to know three positions of these stars: 1. The longitude of the node, and the inclination; 2. The longitude of the perihelion; 3. The distance of the perihelion. To these data should have been added the direction of the motion; for comets move sometimes directly, sometimes they retrograde, and are the sole exceptions to that so remarkable fact, that all the globes of our system move from west to east. In this way then, the curves described by many of these bodies have been determined, and it has been found that they move in ellipses of very great eccentricity, of which the sun occupies one of the foci. Still, in consequence of the imperfect way in which comets were observed by the ancients, most of the elements necessary for the determination of their identity are wanting, which renders it very difficult, in the case of many of them, to assign the periods of their return. It is not altogether impossible even that some of them describe parabolas, that is to say, open curves of which the sun occupies the focus, and consequently that they never return.

As the physical circumstances of the form, the size, and the brilliancy of comets, vary often in the course of a few days, it is not by means of such marks they can be recognised: these, therefore, are entirely neglected, and the attention confined to the *parabolic elements.* But can the identity of two comets that have appeared at different times be always infallibly demonstrated by these means?

If the parabolic elements of two comets are different, we must not be over hasty in concluding that these are two distinct stars; for on passing near a planet, a comet may undergo such a perturbation, that its curve shall be totally changed. But if, on the contrary, the two stars compared together have nearly the same parabolic elements, their identity will be very probable. Still it would not be impossible that two different comets should describe two curves similar in form and position; but, when we reflect to how many different elements this similarity must apply, it is hardly possible to withhold our belief that two comets, which present themselves with the same elements, are one and the same star.

To furnish astronomers with the means of recognising, when a comet appears, whether or not it is one of those already observed, there exists a *catalogue of comets*, in which are regularly inscribed the *parabolic elements* of all those observed. These elements are yet few in number, accurate observations of comets having been confined to modern times. There are but six of these stars whose courses are clearly known by their identification on returning to the sun.

The Comet of 1759.

Halley having calculated, in 1682, the parabolic elements of a comet which appeared at that period, was struck by the analogy between his own results, and those obtained by Kepler, for a comet which had appeared in 1607. He recurred to more ancient observations, and saw that the elements of a comet observed by Apian, in 1531, were very similar to his own. He inferred from this that it was the same comet which would re-appear at nearly equal intervals of time, that is to say, about every seventy-five years; and he ventured to predict from these premises, that it would return about the end of the year 1757, or the beginning of 1758. But Clairaut having calculated that it would be retarded by the action of

Jupiter and Saturn 618 days, it did not actually arrive till the 12th of March, 1759. This is the first comet whose periodicity was foretold, and the truth of the prediction verified.

M. Damoiseau, of the Bureau des Longitudes, calculated the period of its next return. He fixed its perihelion for the 4th of November, 1835. M. de Pontecoulant, who made the same computation, fixed it for the 7th of November. This slight difference of three days in more than seventy-six years and a half, originated in MM. Damoiseau and de Pontecoulant not having adopted the same masses for the perturbing planets.

The inclination to the ecliptic of the orbit of this, which is called Halley's comet, is about 17½°. In 1835 the tail extended over 6° of the sphere. It was visible first at Rome on August 5th, as an exceeding faint telescopic nebula. It passed the perihelion November 16th. After the perihelion, the comet disappeared for two months, but re-appeared January 24th, 1836, in the southern hemisphere, its course carrying it southward in the heavens. It disappeared altogether on May 5th.

The Comet of 1770.

This comet was discovered by Messier in the month of June, 1770, and Lexell found that it had traversed, in five years and a half, an ellipsis, the major axis of which was but thrice the diameter of the earth's orbit.

When this was announced, it naturally excited astonishment that a comet with so short a revolution, and which therefore must have presented itself so often, should not have been perceived by any one before Messier; and the surprise was redoubled when it was not seen to return after intervals of five and a half years, to the different points of Lexell's elliptic orbit. The cause of this mysterious disappearance, which gave rise to so many witticisms, good and bad, is now-a-days perfectly understood. It is at once a consequence and a confirmation of the law of attraction. That the comet was not seen every five and a half years before 1770, was because it then described a totally different orbit from that which it subsequently assumed; and that it was not seen a second time, was because in 1776 its perihelion took place by day, and on its subsequent returns, its orbit had undergone such alterations, that it could not have been recognised for the same comet, even had it been seen from the earth. It was the action of Jupiter on this planet that caused it alternately to approach to and recede from us, by operating in opposite directions.

The Comet of short period.

This comet was discovered at Marseilles, 26th November, 1818, by M. Pons. Its parabolic elements, determined by M. Bouvard, showed it to be the same as that observed in 1805, and on previous occasions. M. Encke, of Berlin, demonstrated that it employs but 1211 days, or about three years and five-tenths, to complete its orbit. Its subsequent appearances have confirmed his calculations.

The orbits of these comets are elongated ellipses, as is shown by their courses. When Encke's comet is nearest to the sun, it is within the orbit of Mercury; but when farthest off from the sun, it nearly approaches the orbit of Jupiter, which is thirteen times as distant as Mercury from the sun. Halley's comet, when in perihelion, was between Mercury and Venus: in aphelion it is just beyond the orbit of Neptune. The inclination of the orbit of Encke's comet to the plane of the ecliptic is about $13\frac{1}{4}°$, and it moves from west to east.

It is like a small round nebula, without any tail; and would be comparatively insignificant, but for the aid which it affords in establishing the undulatory theory of light. According to this theory, space is considered to be filled, apart from the atmospheres of planets, with an extremely rare medium termed *ether*, by the undulations of which light is propagated. This medium, though offering no sensible resistance to the motions of the planets, was thought to be likely, if existing, to impede to a certain extent the passage of so airy a thing as a comet. Accordingly, Professor Encke, having calculated the return of this comet upon the consideration of the *vacuum* of space, the actual time of the comet's return differed two days from the calculated return, in consequence, as asserted, of a resisting operation upon the motion of the comet in its path. But the ultimate effect of this retarding influence was discovered in *hastening*, not in deferring, the time of the appearance of the comet! for, as the all-prevailing ether caused the comet to advance somewhat more slowly, the centrifugal force of the comet was diminished, whereby the solar attraction for it was increased; so that, by being drawn gradually nearer to the sun, the time for its completing its revolution is, in consequence, diminished. In the course of time, therefore, this comet must fall to the sun.

The Comet of six years and three-quarters.

It was discovered at Johannisberg, the 27th of February, 1826, by M. Biela. M. Gambart, who perceived it some days after at Marseilles, determined its parabolic elements, and recognized it as having been before observed in 1085 and in 1772.

This is the comet that so much terrified some people, because it was foretold that it would come in collision with the earth on its return in 1832. It is true that on the 29th October it cut the terrestrial orbit, in a point where the earth arrived a month after, but from which it was then distant more than fifty-millions of miles, since at its mean speed it travels one million eight hundred and seventy-three thousand miles in a day. In 1805, this comet passed ten times nearer to us, that is to say, at the distance of about five millions and a half miles. We shall speak, by-and-by, of the possibility of the earth being shocked by a comet.

The inclination of the orbit of this comet to the ecliptic is 12° 34′, and it accomplishes its course in 2,410 days.

The comet of 1770, referred to before, is obviously not held to be identified as to its elements. The three others have been verified by their due returns to the perihelion, after their due times have respectively elapsed.

Three others have, within the last few years, been discovered and identified by their returns :—

1. The comet discovered by M. Faye in 1843, which describes an elliptical orbit in 7½ years, and was observed on its return in 1850.

2. A comet discovered by De Vico in 1844, which performs its revolution in about 5½ years.

3. Another discovered by Brorsen, in 1846, with a similar period.

The *second* comet before mentioned, is said to have been discovered also by Mr. Hind; as also two others; one on October 18th, 1846, and another in open day, on February 6, 1847. Others have been seen during past years, as also that which was visible for a few days in August last, and one in April of the present year, 1854; but, of these, many have not responded to the calculated orbits, and for others, sufficient time has not yet been afforded.

Physical Constitution of Comets.

This branch of cometary astronomy is not much developed: we shall, however, make known the state of the science as to the *chevelure*, the *nucleus*, and the *tail*.

A great number of those comets which have hitherto been observed have no tail; several present no apparent nucleus; but all appear enveloped in that nebulosity to which has been assigned the name of *chevelure*.

The matter which constitutes the nebulosity is so rare, so transparent, that it allows the feeblest light to traverse it, and the smallest stars can be perceived through it.

In the comets that have a nucleus, the parts of the chevelure near the nucleus are usually rare, transparent, and of little brilliancy; but at a certain distance from the nucleus the nebulosity suddenly brightens, so as to form, as it were, a luminous ring round the comet. Two of these concentric rings have sometimes been seen separated by obscure intervals. Of course, it will be understood that what in projection appears a circular ring, must in reality be a spherical envelope.

When the comet has a tail, the ring is in the form of a semicircle, the convexity of which is turned towards the sun, and from its extremities issue the extreme rays of the tail.

The ring of the comet of 1811 was 28,000 miles thick; and was 33,000 miles distant from the nucleus. The comets of 1807 and 1799 had also rings of 33,000 and 22,000 miles in thickness.

We have said there exist comets that have no apparent nucleus: these are no doubt only globes of gaseous matters; but some there are, that exhibit nuclei similar enough to planets both in form and lustre. These nuclei are usually very small; sometimes, however, they are of large dimensions; several have been measured, varying from 30 to 1,000 miles in diameter.

Some astronomers have sought to prove, upon the strength of different observations, that the nuclei of comets are always transparent; or, in other words, that comets are mere collections of gaseous matters. But, besides that the observations cited in support of this opinion prove nothing in favour of the absolute terms in which it is expressed, they are in direct contradiction with other observations not less deserving of confidence; and from the discussion of these different observations, it seems to result that there are comets that have no nucleus, comets whose nucleus is perhaps transparent, and, lastly, very brilliant comets, the nuclei of which are probably solid and opaque.

We have very little accurate knowledge respecting the tails of comets. Indeed, Herschel says, "There is, beyond question, some profound secret and mystery of Nature concerned in the phenomenon of their tails." We proceed, however, to furnish the substance of what is known, and has been observed.

These luminous trains are usually placed behind the comet, opposite the sun, but sometimes they deviate more or less from this position. It has been found that the tail generally leans towards the region the comet has just quitted. This is, perhaps, an effect of the resistance of the ether, a resistance which acts more strongly on the gaseous tail then on the nucleus. This hypothesis will acquire more probability, if we remark that the deviation is the greater the more the distance from the head. Upon this principle the curve sometimes produced by the tail would seem to be the result of these differences of deviation, and this explanation is sufficiently in keeping with the circumstance that the convexity of the curve is always turned towards the region to which the comet is moving. The difference in density and brilliancy between the nebulous matter and the tail, the form of the latter more distinctly terminated on the side towards which the motion is directed,—all these circumstances, and some others which observations have made known,—are equally and naturally explicable by the hypothesis.

The comet's tail enlarges as it recedes from the head, and the middle region is usually occupied by a dark band, which has been taken for the shadow of the body of the comet. But this explanation is not suitable to every case, whatever be the situation of the tail relatively to the sun. The phenomenon may be more satisfactorily explained by supposing that the tail is a hollow cone, the side of which is of a certain thickness. It is easy to conceive that, if this be the case, the eye must, on looking at the edges of the cone, encounter a greater number of nebulous particles than on looking at the central region : now, as the intensity of the light is in proportion to the number of these particles, the existence of the luminous bands and of the comparatively obscure interval is readily intelligible.

Comets are sometimes seen with several tails. That of 1744, for instance, on the 7th and 8th of March, had six, perfectly distinct, and separated from each other by obscure spaces.

The tails of comets are sometimes of enormous dimensions. Some comets have been seen, as, for instance, those of 1618, of 1680, and of 1769, that reached the zenith while their tails still touched the horizon. That of the comet of 1680 has been estimated at more than one hundred and fourteen millions of miles.

But what are the tails of comets? How are they formed? What are the causes of the chevelure, and of the concentric envelopes of which it is sometimes formed? These questions have not yet been solved in a satisfactory manner.

At first sight it would seem that the nebulosity of comets can be nothing else but a mass of vapour disengaged from the nucleus by the action of the sun; but this very simple explanation does not account for the formation of the concentric envelopes, for the variable position of the chevelure with respect to the sun, for the augmentation and diminution of its volume, &c.

With respect to this latter point, however, we possess some information. Hevelius advanced the assertion that the nebulosity augments in diameter, in proportion as it recedes from the sun; and Newton attempted to explain this by saying, that the tails of comets, being formed at the expense of the chevelure, the latter must diminish in volume as it approaches the sun, and again augment after passing the perihelion, when the tail restores to it the matter it had borrowed from it. It seemed difficult, however, to admit that a gaseous mass should become dilated in proportion as it receded from the sun to pass into colder regions; and the important remark of Hevelius obtained little favour, till the comet of short period came, and most strikingly confirmed it.

Kepler thought the formation of the tails of comets was owing to the impulse of the solar rays detaching and dispersing the lighter particles of the nebulosity. But before this doctrine can be admitted, it must be be proved that the solar rays are endowed with any impulsive force. Now the most delicate experiments have not detected any in them: and if this impulsive force were admitted, it might still be asked, why the tail is not always situated opposite to the sun? why there are sometimes several at such large angles with each other?

why they are formed and vanish in so short a space of time? why some have a very rapid rotary motion? lastly, why there are comets the nebulosity of which appears very delicate, very light, and which yet have no tail?

A host of other theories have been propounded on this subject, more or less ingenious, but they have all broken down when tested by the phenomena.

Are comets luminous in themselves, or do they, like the planets, shine only by a borrowed light? This important question has not yet received a complete solution, but there exist several means of solving it. Should we ever detect the phenomena of phases in the comets, the question would be set at rest. For want of phases, the phenomena of polarization may lead to the same result. Lastly, the following is a third method, the application of which, whenever it can be made, will probably remove every doubt.

Suppose a self-luminous point without sensible dimensions, radiating particles of light all round it through space. If at the distance of one yard, for instance, we receive these luminous particles on the surface of a sphere of one yard radius, they will be equally divided over it. If they be received at the distance of two, three, or one hundred yards,—the spheres being two, three, or one hundred yards in radius,—the luminous molecules will spread uniformly over them, but will diverge from each other in proportion to the enlargement of the surfaces of the spheres. Now, geometry teaches us that the surfaces of spheres increase proportionally to the squares of their radii; the divergence of the rays of light will, therefore, be likewise proportional to the squares of the radii, or, in other words, to the squares of the distances at which the luminous molecules are received; and as the intensity of light which illuminates an object is proportional to the number of luminous rays incident upon it, we arrive at this law, that *the luminous intensity of a point diminishes inversely as the squares of the distances.*

Hitherto we have supposed the case of a luminous point without sensible dimensions; let us now give it some extension.

It is evident that each point of the illuminating surface will project, like the isolated point we have just spoken of, a light which will diminish in the inverse proportion of the squares of the distances. Only, the number of points being augmented, the total quantity of light issued will be greater; whence it follows, that at equal distances the intensity of light is proportionate to the number of radiant points.

We have arrived, then, at this two-fold conclusion, that the *illuminating power* of a surface is, on the one hand, proportioned to its extent, and, on the other, is in the inverse ratio of the squares of the distances.

The consequence of this law is, that the *intensity* of a luminous surface must appear the same, at whatever distance the surface be transported, provided it always subtends a sensible angle.

That this consequence may not at first view appear contradictory to the law from which we have deduced it, we must remark, that the second case concerns the *intensity* of a luminous surface, and the first its *illuminating power*.

When we wish to compare, not the illuminating power, but the luminous intensity of two surfaces, we must take an equal portion of each of them, and see which is the more brilliant. This being laid down, I say that, two luminous surfaces being given, if through openings of equal dimensions we expose equal portions of them to the eye, and if these portions appear to possess the same intensity, they will do so as well when one of the surfaces is transferred to a greater distance, provided always, that the opening through which a part of the surface is seen appear always filled.

For if, on the one hand, each luminous point sends to the eye a number of rays in the inverse ratio of the square of the distance, on the other, the number of luminous points which the eye discovers through the opening, increases in the same direct proportion. The intensity of the visible portion of the luminous surface, will, therefore, have undergone no change. The sun, for instance, as seen from Uranus, appears to have an area of 25″. Well then, let us cut out upon the sun's disk, by means of a screen with a hole in it, a circular surface of 25 seconds, and we shall have the sun of Uranus both in size and lustre.

Let us now see to what use these principles may be turned for solving the question we have in view, namely, whether the comets are or are not self-luminous.

The question resolves itself into this: in what manner does a comet cease to be visible? If its disappearance is the result of an excessive diminution of its dimensions, and not of a weakening of its light, the star is self-luminous; but if, the comet being still of large dimensions, its light gradually fades, and finally becomes extinct, that light no doubt was borrowed.

The observations hitherto made, seem to prove that this cause of the disappearance is the true one, and, consequently, that the comets only reflect a borrowed light.

Nevertheless, this consequence may possibly not be rigorously exact. It is now ascertained, as already stated, that the nebulosity of comets increases as they recede from the sun. May it not be that this progressive dilation causes a gradual weakening of the light? Henceforth then, it will be necessary to investigate the cause of the dilation, and to show that it is insufficient to explain the disappearances of comets. This complication of the problem cannot present any great difficulties.

There are some questions connected with cometary Astronomy, which we shall examine in succession.

Have comets a sensible influence on the course of the seasons?

This question has been decided in the affirmative by popular prejudice, fortified by examples; among which the fine comet of 1811, and the abundant harvest that followed it, are not forgotten. A few words will suffice to confute this error. Let us first speak of facts; theoretical considerations will follow after.

The inquiry has been made, on examining the thermometrical observations which are taken several times daily in observatories, whether the mean temperatures of years distinguished by comets, are higher than those of other years: no sensible difference has been discovered.

The result of these observations is in accordance with theory. By what mode of action, indeed, could comets modify our temperature? These stars can only act at a distance upon the earth by attraction, by the luminous and calorific rays they emit, and by the gaseous matter of their tails, which might possibly expand into our atmosphere.

The attractive force of the comets might, certainly, if it was strong enough, occasion tides similar to those caused by the moon; but we cannot see how an elevation of temperature should arise from it.

Neither could the calorific or luminous rays, which comets emit or reflect, produce this effect, for they are of much less intensity than those that reach us from the moon, and which, concentrated in the foci of the largest lenses, produce no sensible effect.

Lastly, the introduction of a part of the tail of a comet into the atmosphere, cannot be assigned as the cause of the elevation of temperature attributed to these bodies, since the tail of the comet of 1811, for instance, which was 100 millions of miles long, never reached the earth, nor came within several millions of miles of it.

Is it possible that a comet should come in collision with the earth, or with any other planet?

Comets move in all directions, in very elongated ellipses, which traverse our solar system and cross the orbits of the planets. It is not, therefore, out of the range of possibility that they should come in contact with some of these stars, and the shock of the earth by a comet is rigorously possible: at the same time it is extremely improbable.

The evidence of this proposition will be complete, if we compare with the small volume of the earth and of comets the immensity of the space in which these globes move. The doctrine of chances affords us the means of estimating numerically the probability of such a collision, and shows that there is but one such chance in 281 millions: that is to say, that, on the appearance of a new comet, the odds are 281 millions to one that it will not strike against our globe. Hence we see how absurd it would be in man to concern himself with the apprehension of such a danger, during the few years he has to pass upon the earth.

Were this collision indeed to take place, its effects would be tremendous. Were the earth dashed against, so that its motion in space should be destroyed, everything not adhering to its surface, as animals, water, &c, would set off from it with a velocity of twenty miles per second. If the shock only retarded the rotary movement, the seas would spring from their basins, the equator and the poles would be changed. But let us allow the author of the *Mécanique Céleste* himself to describe their terrible effects: "The axis and the rotary motion being changed, the seas would abandon their old positions, and rush violently towards the new equator; a great part of the human and animal races drowned in this universal deluge, or destroyed by the violence of the shock given to the terrestrial globe, entire species annihilated; all the courses of human industry confounded;—such would be the disasters ensuing from a collision with a comet. We now see why the ocean has covered the loftiest mountains, on which it has left the most incontestible traces of its presence; we see why it is that animals and plants of southern climes have been able to exist in the north, where their remains and their footsteps are now discoverable; lastly, we can explain the novelty of the moral world, the monuments of which hardly ascend backwards more than 5,000 years. The human species, reduced to a small number, and to the most deplorable condition, solely occupied during a very long space of time with care of self preservation, must necessarily have wholly lost the memory of arts and sciences; and when at length the progress of civilization made it feel the nature of its wants, it had to begin everything anew, as if men had then for the first time been placed upon the earth."

Has our globe ever been struck by a comet, as the author just quoted supposes?

Men of profound acquirements have asserted, that the axis on which our globe turns has not always been the same. This opinion they have supported by reasonings drawn from the fact, that the several degrees measured on each meridian between the pole and the equator, combined two and two, do not all give the same value for the flattening at the poles. In the difference of these results they fancy they see a proof, that, at the time when the earth, still in the fluid state, assumed its sphericity, it did not turn on the same axis it does now.

But it is easy to convince ourselves that the change in the axis cannot be the cause of the discrepancies between the values of degrees furnished by observation, and those which would result from a certain theory of flattening; for this disagreement does not follow a regular and gradual course, but an irregular and capricious one. It is the result of local attractions, of geological accidents, which we now know can exist as well in the plains as in the neighbourhood of mountains.

But let us pass on to other considerations.

If we give a rotary motion to a spherical and homogeneous body, freely suspended in space, its axis of rotation remains perpetually invariable. If this body has quite a different form, its axis of rotation may change every moment; and this multitude of axes, round which it executes only a part of its rotation, are called the *instantaneous axes of rotation.* Lastly, geometry demonstrates that every body, whatever be its figure and its variations of density from region to region, may turn in a constant and invariable manner round three axes perpendicular to each other, and passing through its centre of gravity. These are called the *principal axes of rotation.*

This being premised, let us inquire whether the axis round which the earth turns is an instantaneous or a principal axis. In the former case the axis will change every instant, and the equator will undergo corresponding displacements. Terrestrial latitudes, which are no more than the angular distances of the several places from the equator, will suffer the like changes. Now, observations of latitude, which are made with extreme nicety, indicate no changes of this kind; terrestrial latitudes are constant: the earth, therefore, turns on a *principal axis.*

From this it is easy to deduce a proof that the earth has never sustained the shock of a comet; for the effect of this would have been to substitute an instantaneous for the principal axis, and terrestrial latitudes would have been subjected to continual alterations, which observations do not discover. It is true, it is not mathematically impossible that the effect of a shock should be to substitute a principal for an instantaneous axis, but this case is so improbable, that it scarcely weakens the force of the demonstration.

In what we have just said, we have proceeded on the supposition that the earth is a body entirely solid. But it may be that its interior is still liquid, as it is in the present day generally supposed to be. Can we in this latter case deduce, with the same certainty, from the constancy of terrestrial latitudes, a proof that the earth has never been struck by a comet?

We think not: for, after the shock (the immediate effect of which would have been violently to precipitate a part of the internal liquid mass towards the new equator, where it could not have lodged but by bursting through the solid crust of the globe, the continual displacement of the instantaneous axis inferring an incessant alteration in the shape of the fluid mass), it would not be impossible that the continual friction of the liquid against the solid shell should bring about a gradual diminution in the length of the curve described by the extremities of the instantaneous axis, and, consequently, in the long run, a motion of rotation round a principal axis.

Is it possible that the earth should pass through the tail of a comet, and what consequences would this produce for us?

Comets have in general very little density: they must, therefore, very feebly attract the matter forming these tails, since attraction operates in proportion to the mass.

Now we can easily conceive that the earth, the mass of which is much more considerable than that of most comets, may attract to itself and draw into its atmosphere a part of the tails of those bodies, especially if we reflect that the extreme portions of the tails are sometimes at enormous distances from the heads.

As for the consequence of the introduction of a new gaseous element into our atmosphere, it would depend on the nature and the abundance of the matter thereof, and might occasion the total or partial extinction of animal life. But science has not yet had an opportunity of recording an event of this nature; and the connection which many persons have sought to trace between the appearances of comets and the revolutions of the moral and physical world, rests on no foundation.

Were the dry fogs of 1783 *and* 1831 *constituted of matter detached from the tails of comets?*

The fog of 1783 lasted a month. It began almost on the same day in places very remote from each other. It extended from the north of Africa to Sweden; it occupied too a large part of North America, but it did not extend over the sea. It rose above the loftiest mountains. It did not appear to be carried by the wind; and the most abundant rains, the strongest winds, were unable to dissipate it. It gave out a disagreeable odour, was very dry, did not at all affect the hygrometer, and possessed the property of phosphorescence.

Such are the facts: it has been sought to explain them on the supposition that this fog was the tail of a comet. But if that were so, why was the head of the comet never seen, for the fog was not so dense as to hinder the stars from being visible at night? The objection is fundamental, and saps the hypothesis at its base.

This explanation is still less applicable to the fog of 1831, which so much resembled that of 1783; for this fog, not having covered the whole surface of Europe, the invisibility of the comet would have been still more surprising. Besides, every point between the parallels should have been successively covered by reason of the earth's rotation, and yet the fog terminated at fifty leagues from the coasts.

The origin of these extraordinary fogs may be more satisfactorily explained, as proceeding from the interior revolutions by which our globe is often agitated In 1783, the same year as the fog appeared, Calabria was devastated by frightful earthquakes, that buried more than 40.000 of its inhabitants. Mount Hecla, in Iceland, made one of the greatest eruptions on record; new volcanoes issued from the bosom of the sea, &c.

Is it then so difficult to admit that gaseous matters, of an unknown nature, should have issued from the bowels of the earth, torn by these violent commotions, and may not this explanation be consistent with the remarkable circumstance, that the fog did not exist on the high seas? But we merely wish to point out one of those hypotheses on which it would be possible to explain the formation of dry fogs, without having recourse to the immersion of the earth in the tail of a comet.

There exists on the western coast of Africa something similar to the phenomenon in question. It is a dry and periodical fog, conveyed by a wind called *harmatan*, which makes furniture crack, warps the covers of books, dries up plants, and exercises over the human body a no less unfavourable influence. This fog, too, is confined to the land: its cause is unknown

Has the moon ever come in collision with a comet?

We have seen that the satellite turns on itself in precisely the time it takes to perform its revolution round the earth. The isochronism of these motions is explained by supposing, that at the time when the moon, still fluid, was tending to assume the form corresponding to its rotation, the attraction of our earth elongated it, and its greater axis directed itself towards the centre of the earth.

Now, if a comet had ever struck the moon, the shock would have disturbed the harmony existing between the motions of rotation and revolution, and consequently have caused the greater axis of the moon to be displaced from the line directed towards the centre of the earth. This great axis would then, like a pendulum, perform oscillatory motions round our earth; but nothing of the sort existing, we must therefore conclude that the moon has never been shocked by a comet.

Has the moon formerly been a comet?

The Arcadians, according to Lucian and Ovid, believed themselves more ancient than the moon Their ancestors, they said, had inhabited the earth before the moon existed. This singular tradition has suggested the question, whether the moon may not be an old comet, which, passing near the earth, became its satellite.

There is no impossibility in that; but the reasons given in support of this conjecture have not the slightest value. As the comet moon, that it should become a satellite of the earth, must necessarily have had a short perihelion distance, speculators will have it that in the burnt appearance of its mountains, exist evidences of the enormous heat it must have endured in passing so near to the sun. This is a confusion of words. It is very true, the appearances of ancient volcanic derangements give to some points of the moon's surface a burnt aspect, but nothing exists to indicate, in the present day, what temperature it may formerly have sustained

Furthermore, the partisans of this opinion will have some difficulty in explaining why the moon has no sensible atmosphere, whereas all the comets that have yet been seen, present themselves to us enveloped in a gaseous covering If the moon is an old comet, what has she done with her *chevelure*, or hair?

Is it possible that the earth should become the satellite of a comet, and if so, what lot would in that case await us?

That a comet should possess itself of the earth, and make it its satellite, it is enough to give it a mass sufficiently considerable, and to make it pass near us. It will, beyond doubt, take our globe away from the attraction of the sun, and carry it with it in its revolution round that body. But the great mass with which the supposed comet must be endowed, and the small distance at which it must pass from the earth, render this event of little probability.

However, as it is rigidly possible that the thing may happen, let us inquire what would under these circumstances be the fate of the earth's inhabitants. Would our globe undergo, as has often been asserted, extreme vicissitudes of temperature? Would it be by turns vitrified, evaporated, congealed? Would it become uninhabitable, and would all the animal and vegetable races on its surface be annihilated?

Let us suppose, in order to reply to these questions, that the earth becomes a satellite to a comet that approaches closely to the sun, and recedes to a great distance from it,—the comet of 1680, for instance.

This comet, completing its revolution in 575 years, travels over an ellipsis, the major axis of which is 138 times greater than the mean distance of the earth from the sun. Its perihelion distance is extremely short. Newton has calculated that at its perihelion of the 8th of December, 1680, it must have sustained a heat 28,000 times greater than that of the earth in summer: he has estimated it at 2,000 times that of red-hot iron.

But this result cannot be admitted. To solve the problem that Newton proposed to himself, it would be necessary to know the state of the surface and of the atmosphere of the comet in 1680: nay more, put the earth itself in the comet's place, and the question is not yet solved. Doubtless the earth will at first undergo a temperature 28,000 times greater than summer heat; but soon all the liquid masses that cover it, being converted into vapour, will produce thick layers of clouds, that will diminish the action of the sun in a proportion impossible to assign numerically.

Would it be more easy to determine the temperature of our globe, when it shall have accompanied the comet to its aphelion? If we consider only the relations of distance, the earth should then be 19,000 times less heated than it is in summer; that is to say, no longer receiving any appreciable heat from the sun, it should only possess that quantity not yet dissipated, which it should have imbibed at its perihelion; and, if it had lost all this, it should be at the temperature of space or thereabouts, which cannot descend below 122° Fahrenheit, according to the ingenious computations of Fourier.

Now experience proves that man can sustain degrees of cold of from 56° to 58° below zero of Fahrenheit's thermometer, and a heat of 266°, when he is placed in certain hygrometric conditions. There is nothing, therefore, to prove that, in the hypothesis that the earth should become the satellite of a comet, the human race must necessarily perish from thermometric changes.

These considerations as to the limits between which the temperatures of the celestial globes may oscillate, are fitted to render their *inhabitability* less problematical in the eyes of persons who feel a difficulty in conceiving the existence of beings formed upon a system of organization totally different from our own.

Was the deluge occasioned by a comet?

It is impossible in the present day to doubt that our globe has been frequently convulsed by frightful revolutions, and that the waters of the sea have repeatedly inundated and abandoned the continents. To explain these tremendous cataclysms, the aid of comets has been invoked. Let us examine these explanations.

Whiston proposed one, which he had adapted to all the circumstances of the deluge described by Moses. He supposes, and there is nothing inadmissible in the supposition, that the comet of 1680 was in the neighbourhood of the earth when the deluge happened. He makes the earth to be an old comet, to which he gives a solid nucleus, and two concentric orbs,—the nearer to the centre formed of a weighty fluid, and the other of water; on this latter reposes the solid crust on which we walk. This being premised, he places the comet of 1680 at no more than eight or ten thousand miles from the earth. The comet, by reason of its great proximity, exercising a powerful attraction over the interior fluids, produced an immense tide that burst the solid crust, and precipitated the fluid mass upon the continents. This was the *bursting open the fountains of the great deep.*[*]

As for *the opening of the cataracts of heaven,*[*] as Whiston could not see this in ordinary rain, forty days and nights of which would have produced too inconsiderable results, he sought it in the atmosphere, and in the tail of his comet, which spread over our globe a sufficient quantity of aqueous vapours to supply the most violent rains.

This theory, which long enjoyed great celebrity, will not sustain any deep investigation.

We shall not speak of the constitution attributed by Whiston to the earth, and which is not admitted by modern geology. We shall confine ourselves to remarking, that his gratuitous supposition of the mass and the proximity of the comet of 1680, is not sufficient to explain the phenomena.

In fact, since the motion of the star must have been extremely rapid, its attraction could not have been exerted for a sufficient length of time upon the several points, to cause the great tide of which we have spoken.

Besides, this famous comet passed near the earth the 21st of November, 1680; and it is demonstrated that at the epoch of the deluge its distance was not less. For all that, it did not *burst the fountains of the great deep,* nor *open the cataracts of heaven.* Whiston's explanations are therefore inadmissible.

Halley, who took a more general view of the question, endeavoured to account for the presence of marine productions far from the seas, and on the highest mountains, by the shock of a comet coming in contact with the earth.

We have already examined the question, whether such a shock has ever taken place. We shall here add that, supposing the affirmative of this question, we should vainly seek, in the effects of such a collision, a satisfactory explanation of the phenomena. The stratification of the marine deposits, the extent and regularity of the strata, their positions, the perfect preservation in them of the most delicate and most fragile shells, all exclude the idea of a violent transfer of place, all prove that the deposits have been made where they are found.

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[*] Gen. vii. 11.

The explanation of these phenomena presents no difficulties, since science has been enriched by the brilliant ideas of M. Elie de Beaumont upon the formation of mountains by way of uplifting of the land.

Have the several points of our globe suddenly changed their latitude in consequence of the shock of a comet?

In every region of Europe are found fossil bones of the rhinoceros, the elephant, and other animals, which now could not live in our latitudes. We must therefore suppose, either that Europe has experienced a considerable cooling down, or that in some of the violent commotions our earth has undergone, these fossil remains have been swept along by currents carrying them from south to north.

But these explanations are inapplicable to two circumstances discovered in modern times, and which have greatly engaged the attention of the learned. On the banks of the Wilhoui in Siberia, in 1771, was found, at a few feet below the surface, a rhinoceros in a state of perfect preservation; neither its flesh nor its skin was in the slightest degree damaged. Some years later, in 1799, there was found near the mouth of the Lena, on the shores of the Icy Sea, a great elephant enclosed in a mass of congealed mud, and so well preserved that dogs ate of its flesh.

How are we to account for the presence of these two large animals at such a distance from the countries in which they lived? Here the operation of currents cannot be thought of; for, had not the animals been frozen immediately after death, they would have suffered putrefaction. They must, therefore, have lived in the places where they have been found. Thus, on the one hand, Siberia must formerly have possessed an elevated temperature, since elephants and rhinoceri lived in it; on the other, the catastrophe in which these animals perished, must have suddenly rendered those regions icy.

There remains but one step from these deductions to the admission of the shock of the earth by a comet; for we know no other cause capable of producing an abrupt alteration in the latitudes of our globe.

Is this explanation admissible? We think not.

In the first place, is it authenticated that the elephant of the Lena, and the rhinoceros of the Wilhoui, could not have lived under the actual climate of Siberia? We may venture to doubt this; for these animals, otherwise similar in size and form to those that now inhabit Africa and Asia, are distinguished from them by a circumstance very deserving of note: they possessed a species of fur. The skin of the rhinoceros was beset with stiff hairs, about a third of an inch long, and that of the elephant was covered with black hairs and with a reddish wool; its neck was furnished with a long mane. These remarkable peculiarities impress us strongly with the notion that these animals were created to live in a northern region.

Again, a celebrated traveller has recently established the fact, that the royal tiger, which belongs to the hottest countries, still lives in Asia in very elevated latitudes, that it advances in summer as far as to the western slope of the Altaï mountains. Why might not the furred elephant have transported himself in summer as far as to Siberia? When arrived there, a very common accident, a snow-slip, for instance, was sufficient to bury him under frozen layers capable of preserving him from all putrefaction: for in those latitudes, the earth, to a depth of from twelve to fifteen feet, remains eternally frozen.

It is, therefore, by no means necessary, if we would account for the discoveries on the Lena and Wilhoui, to have recourse to the supposition of a comet's collision with the earth. Moreover, this hypothesis, the inadmissibility of which we have shown elsewhere, would in this case be of no avail. For, if the partisans of this opinion will absolutely have it, that Siberia was formerly in the vicinity of the equator, it must necessarily be admitted that it was then covered by a fluid dilatation of fourteen miles thick, produced by the rotary motion of the earth. Under these circumstances, where should we find footing for our rhinoceros and our elephant?

M. Elie de Beaumont has ingeniously connected the solution of the problem created by the discovery of the Siberian elephants with his theory of the formation of mountains. He supposes that the river Tian Chan having risen in winter in a country the valleys of which abounded with elephants, and the mountains of which were covered with snow, the warm vapours issuing from the earth's bosom at the moment of the convulsion partly melted this snow, and produced a great current of air at the temperature of zero. This current laying hold of the carcases of these animals which it found in its way, carried them with it in eight days, before decomposition could set in, into the latitudes of Siberia, where the frost immediately seized them.

What is the cause of the depression of the soil exhibited by a great part of Asia? Is it the shock of a comet?

There is in Asia a vast region of upwards of 50,000 square miles, occupied in great measure by the Caspian Sea, and containing populous cities, which exhibits a depression of three hundred and twenty-nine feet below the level of the Black Sea and the Ocean.

To explain this enormous sinking of a whole country, recourse has been had, as in so many other circumstances, to the supposed collision of the earth with a comet.

This explanation, proposed by Halley, is now-a-days abandoned: the earth, we have seen, has never come in collision with a comet, and the geographical phenomenon in question can be explained without this supposition.

It is an opinion, generally admitted in the present day, that mountains have been formed by the upheaving of their materials; that they have issued from the bosom of the earth by breaking violently through its crust. Now the necessary consequence of such an uplifting, is the formation of a void in the surrounding soil, and the possibility of that soil subsequently falling in.

Let us cast our eyes on the map; we shall see that

Asia abounds more in upheaved masses than any other quarter of the globe, and that round the depressed region of which we have spoken, tower a multitude of great chains: the Iran, the Himalayan, the Kuen Lun, the Tian Chan, the Caucasian chain, the mountains of Armenia, those of Erzerum, &c. Why, therefore, should not the elevation of these great masses have caused a corresponding sinking in the intermediate soil?

This explanation will appear still more plausible, if we add, that, in the regions we are speaking of, the soil has not yet arrived at a state of complete stability, and that the bottom of the Caspian Sea, for instance, exhibits alternations of depression and elevation.

LECTURE XII.

ECLIPSES, LUNAR AND SOLAR—HALLEY'S DESCRIPTION OF A TOTAL ECLIPSE—RECENT OBSERVATIONS.

ECLIPSES, like comets, were formerly objects of popular terror, but every one now knows that these phenomena are consequences of the laws of nature, and that they are predicted with as much accuracy as the return of day and night.

Eclipses of the Moon.

The earth being an opaque and round body, the sun can enlighten but a part of it at a time; whence it follows, that it projects a shadow opposite to that luminary. What is the form of this shadow? What are its dimensions? If the sun and the earth were of the same size, the shadow would be cylindrical, and of infinite extent; but, as the earth is much smaller than the sun, the shadow it projects forms a cone, long enough to reach the moon, but not sufficiently long to arrive at Mars: it has been calculated that this cone is 800,000 miles in length. On the sides of the cone are shadows less dense, formed by the interruption of a part only of the sun's rays, the intensity of which shadows diminishes in proportion as these recede from the conical shadow. This intermediate shade between pure shadow and light, is called the *penumbra*. To determine its limits, we may draw lines extending from the edges of the sun and grazing the earth's surface. These prolonged lines form a truncated cone, which is that of the penumbra. Thus, let S be the sun, E the earth. The cone of shadow *abf* terminates in *f*, where the rays issuing from the sun's edges meet after having grazed the earth's surface, and the truncated cone *abcd*, is that which forms the penumbra.

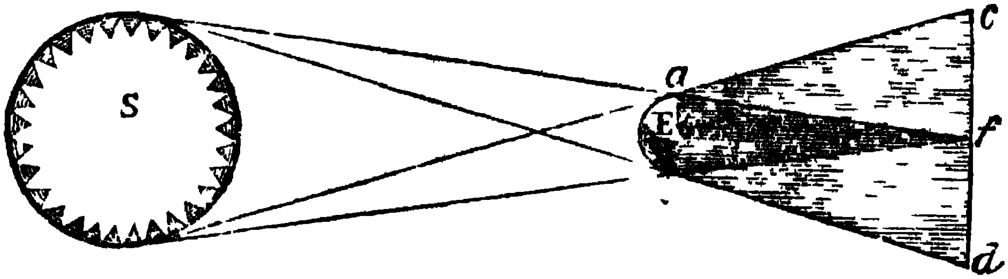

Fig. 28.

When the earth, then, becomes situated between the sun and the moon, the latter must be covered with darkness, and there will be an eclipse of the moon. The eclipse will be total or partial, according as the moon plunges wholly or in part into the cone of shadow. It will be central, if the centre of the moon coincides exactly with that of the terrestrial shadow.

Were the plane in which the moon moves not inclined to the ecliptic, a lunar eclipse would take place at every full moon: but, as the orbit it describes cuts the ecliptic according to the line of the nodes, it takes various positions relatively to this plane. If at its opposition it is not in the nodes, it will skim the earth's shadow, without penetrating it, and this is what most frequently occurs; but, if the line joining the centres of the earth, the sun, and the moon, is a straight line, or nearly so, as is the case when the moon is in or very near the nodes, there will be an eclipse.

To express the extent of eclipses, the moon is supposed to be divided into twelve equal and parallel zones, called digits. Thus, when a third, or one-half of the disk is eclipsed, we say that the eclipse is of four or six digits. If the eclipse is total, and the diameter of the shadow is greater than that of the moon, we say that the eclipse is of more than twelve digits, and the number of digits is proportionally determined.

All the eclipses of the moon, are completely visible from all parts of the earth that have the moon above their horizon, are everywhere of the same size, and have the same commencement and the same end. It is always the eastern side of the moon's disk that first plunges into the shadow, that is to say the left side, when we look towards the south.

The moon in her approach to the cone of shadow loses her brilliancy by insensible degrees, because she then enters the penumbra, the intensity of which, we have seen, gradually increases up to the conical shadow. When arrived in this shadow, it does not usually disappear in it completely, even when the eclipse is total, because it receives some rays of light, that reach it in consequence of refraction, even within the cone. It has sometimes, however, been seen to disappear totally, when the atmosphere, loaded with clouds, sent it no refracted light.

We have said that eclipses of the moon are visible from all points that have the moon above their horizon, and that they are for all these points of the same extent; but we must add, that the apparent time when they are seen, varies according to the longitude, and thus they furnish a means of determining the longitude of the place where they occur. A total eclipse of the moon never exceeds two hours, and may be shorter than that period.

Eclipses of the Sun.

When the moon interposes herself between the sun and the earth, the former may be eclipsed. The eclipse is *partial* when the moon hides only a part of the sun's disk; *total*, when she covers the whole of it; *annular*, when the sun, masked by the moon, projects all round in the form of a luminous ring; lastly, it is *central* when the spectator's place is in the prolongation of the line joining the centres of the sun and moon.

The moon being nearly of the same figure as the earth, her shadow and her penumbra are formed in the same manner: only, as she is much smaller, her cone of shadow can never cover more than a portion of the earth's surface. Every one knows, in fact, that a solar eclipse never takes place at the same time all over the earth, and it is easy to show that the same eclipse of the sun which is total for one point on the earth, may be invisible at another. But, as the moon passes before all the points of the sun's disk, she successively hides it from different parts of the earth in the direction of her motion from west to east. In most solar eclipses, the moon's disk is clothed with a faint light, proceeding from the reflection caused by the illuminated part of the earth.

The apparent diameter of the moon, when at its maximum, exceeds the apparent minimum diameter of the sun, by 2′ 1″. Thus the longest central and total solar eclipse that can happen, will equal the time necessary for the moon to travel 2′ 1″ of a degree; that is, about 3′ 40″ of time.

But, as the apparent diameter of the moon. when at its minimum, is less than the apparent diameter of the sun at its maximum, by 3′ 47″, this eclipse will be central and *annular*, and will last about seven minutes.

Solar eclipses, like lunar, are counted by digits.

The following is the manner in which the general phenomenon of solar eclipses takes place:—Let S be the sun, YY the earth, M the moon, and AMP the orbit of the moon. If we draw the lines W*ce* and V*de*, the obscure space *cde*, comprised between the lines, will be the moon's cone of shade; the lines W*dh* and V*cg* determine the limits of the penumbra at *abcdgh*. This being premised, the moon moves in her orbit from west to east, as from M to P. An observer situated at *b*, will see the eastern limb of the moon touch the western limb of the sun W, and the eclipse will begin for him. But at the same moment the western edge of the moon at *c*, quits the eastern side of the sun at V, and the eclipse terminates for the spectator at *a*; there is, therefore, a partial eclipse of the sun for all the points between *a* and *b*; but it is evident, from the figure, that the sun is totally eclipsed but for a small part of the earth at a time at *e*, since it is only the extremity of the cone of complete shadow that reaches the earth.

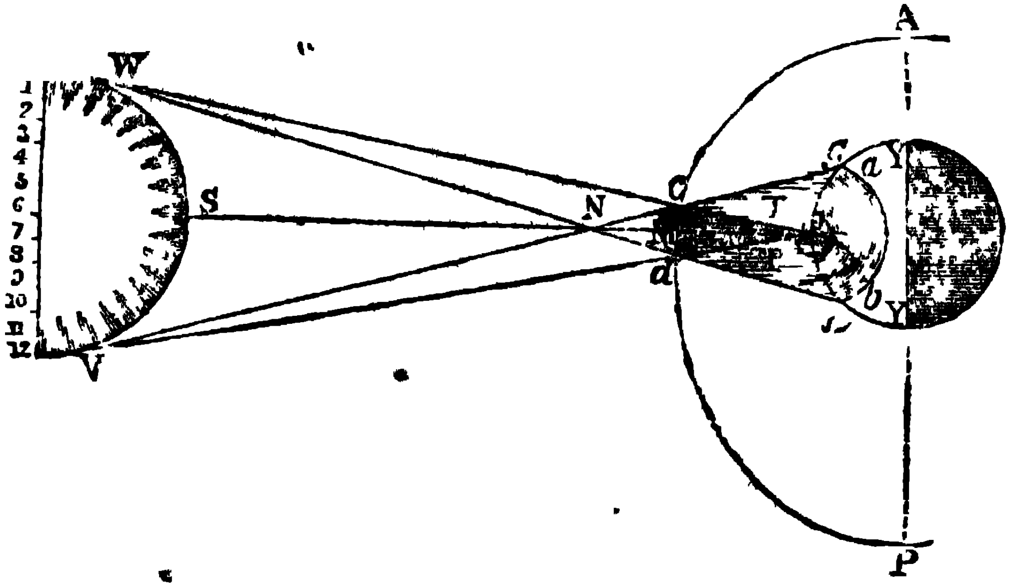

Fig. 29.

Eclipses recur only at somewhat long intervals of time: they can only happen at the syzygies: the synodic revolution of the nodes taking place but in $346^d\ 14^h\ 52'\ 16''$, it is to the synodic revolution of the moon nearly in the ratio of 223 to 19. After a period of 223 lunations, the sun and the moon, therefore, meet in the same position with respect to the lunar node. This remark serves for predicting the return of eclipses. Calculation has demonstrated that they occur over again after the lapse of about every eighteen years and three-fifths; due allowance being made for the motion of the sun, which attains the same longitude with the moon in the lapse of nineteen years.

As total eclipses of the sun are very rare, the following description, given to Halley by one of his friends, will not, perhaps, be without interest for the reader:*—

"I send you, according to promise, my observations of the solar eclipse, though I fear they will not be of much use to you. Not being furnished with the necessary instruments for measuring time, I confined my views to examining the spectacle presented by nature under such extraordinary circumstances, a spectacle which has hitherto been neglected or imperfectly studied. I chose for my point of observation a place called Haradow Hill, two miles from Amesbury, and east of the avenue of Stonehenge, of which it closes the vista. In front, is that celebrated edifice, upon which I knew that the eclipse would be directed. I had, moreover, the advantage of a very extensive prospect in every direction, being on the loftiest hill in the neighbourhood, and that nearest to the centre of the shadow. To the west, beyond Stonehenge, is another rather steep hill, rising like the summit of a cone above the horizon. This is Clay Hill, adjoining Warminster, and situated near the central line of darkness, which was to set out from this point, so that I could be aware in time of its approach. I had with me Abraham Sturgis and Stephen Evans, both natives of the country, and able men. The sky, though overcast, gave out some straggling rays of the sun, that enabled me to see around us. My two companions looked through the blackened glasses, while I made some reconnaissance of the country. It was half-past five by my watch when they informed me that the eclipse was begun. We watched its progress, therefore, with the naked eye, as the clouds performed for us the service of coloured glasses. At the moment when the sun was half obscured, a very evident circular rainbow formed at its circumference, with perfect colours. As the darkness increased, we saw the shepherds on all sides hastening to fold their flocks, for they expected a total eclipse of an hour and a quarter duration.

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* I have sought in vain for this letter among the books and MSS. of our public libraries, and have found myself reluctantly compelled to re-translate it from the French version. An eminent astronomer informs me that the author was Dr. Stukeley; he remembers to have seen the letter somewhere, but his kind endeavours to aid my search for it have been unavailing.—TRANS.

"When the sun assumed the appearance of the new moon, the sky was tolerably clear, but it was soon covered with deeper clouds. The rainbow then vanished, the steep hill I have named became very obscure, and on each side, that is, north and south, the horizon exhibited a blue tint, like that it possesses in summer towards the close of day. Scarcely had we time to count ten, when Salisbury spire, six miles to the south, was enveloped in darkness. The hill disappeared entirely, and the deepest night spread around us. We lost sight of the sun, whose place till then we had been able to distinguish in the clouds, but whose trace we could now no more discover than if it had never existed.

"By my watch, which I could scarcely discern by some light that reached us from the north, it was thirty five minutes past six. Shortly before, the sky and the earth had assumed, literally speaking, a livid tint, for it was a mixture of black and blue, only the latter predominated on the earth and at the horizon. There was also much black diffused through the clouds, so that the whole picture presented an awful aspect, that seemed to announce the death of nature.

"We were now enveloped in a total and palpable darkness, if I may be allowed the expression. It came on rapidly: but I watched so attentively, that I could perceive its progress. It came upon us like rain, falling on our left shoulders (we were looking to the west), or like a great black cloak thrown over us, or like a curtain drawn from that side. The horses we held by the bridle seemed deeply struck by it, and pressed closely to us, with marks of extreme surprise. As well as I could perceive, the countenances of my friends wore a horrible aspect. It was not without an involuntary exclamation of wonder I looked round me at this moment. I distinguished colours in the sun, but the earth had lost all its blue, and was entirely black. A few rays shot through the clouds for a moment, but immediately afterwards the earth and the sky appeared totally black. It was the most awful sight I had ever beheld in my life.

"North-west of the point whence the eclipse came on, it was impossible for me to distinguish in the least degree the earth from the sky, for a breadth of sixty degrees or more. We looked in vain for the town of Amesbury, situated below us; scarcely could we see the ground under our feet. I turned frequently during the total darkness, and observed that, at a considerable distance to the west, the horizon was perfect on both sides, that is, to the north and to the south; the earth was black, and the lower part of the sky clear; the obscurity, which extended to the horizon in those points, seemed like a canopy over our heads adorned with fringes of a lighter colour, so that the upper edges of all the hills, which I recognised perfectly by their outlines, formed a black line. I saw perfectly that the interval between light and darkness, observable in the north, was between Martinsell Hill and St. Anne's; but to the south it was less distinctly marked.

"I do not mean to say that the line of shadow passed between these two hills, which were twelve miles distant from us; but as far as I could distinguish the horizon, there was none behind; and for this reason: my elevated position enabled me to see the light of the sky beyond the shadow; still that yellowish-green line ot light I saw was broader towards the north than towards the south, where it was ot a tan-colour. At this period it was too black behind us, that is, to the east, looking towards London, to enable me to see the hills beyond Andover, for the anterior extremity of the shadow lay beyond that place. The horizon was then divided into four parts, differing in extent, in light, and in darkness. The broadest and least black was to the north-west, and the longest and brightest to the south-west. The only change I could perceive during the whole time the phenomenon lasted, was that the horizon divided into two parts—one clear, the other obscure. The northern hemisphere then acquired more length, brightness, and breadth, and the two opposite parts coalesced.

"Like the shadow in the beginning of the eclipse, the light approached from the north, and fell on our right shoulders. I could not, indeed, distinguish on that side either defined light or shadow upon the earth, which I watched attentively, but it was evident that the light returned but gradually and with oscillation: it receded a little, advanced rapidly, till at last, with the first brilliant point that appeared in the sky, I saw plainly enough an edge of light that grazed our sides for a considerable time, or brushed our elbows from west to east. Having good reason, therefore, to suppose the eclipse ended for us, I looked at my watch, and found that the hand had traversed three minutes and a half. The hill-tops then resumed their natural colour, and I saw a horizon at the point previously occupied by the centre of the shadow. My companions cried out that they again saw the steep hill towards which they had been looking attentively. It still, indeed, remained black to the south-east, but I will not say that the horizon was difficult to discover. Presently we heard the song of the larks hailing the return of light, after the profound and universal silence in which everything had been plunged. The earth and sky appeared then as they do in the morning before sunrise. The latter was of a greyish tint, inclining to blue; the former, as far as my eye could reach, was deep green or russet.

"As soon as the sun appeared, the clouds grew denser, and for several minutes the light did not increase, just as happens at a cloudy sunrise. The instant the eclipse became total, till the emersion of the sun, we saw Venus, but no other stars. We perceived at this moment the spire of Salisbury Cathedral. The clouds not dispersing, we could not push our observations farther: they cleared up, however, considerably towards evening. I have hastened home to write this letter. So deep an impression has this spectacle made on my mind, that I shall long be able to recount all the circumstances of it with as much precision as now. After supper I made a sketch of it from memory, on the same paper on which I had previously drawn a view of the country.

"I will own to you I was, methinks, the only person in England who did not regret the presence of clouds : they added much to the solemnity of the spectacle, incomparably superior, in my opinion, to that of 1715, which I saw perfectly, from the top of the belfry of Boston, in Lincolnshire, where the sky was very clear. There, indeed, I saw the two sides of the shadow coming from afar, and passing to a great distance behind us; but this eclipse exhibited great variety, and was more awfully imposing; so that I cannot but congratulate myself on having had opportunities of seeing, under such different circumstances, these two rare accidents of nature."

We cannot fail to remark how similar are all the circumstances attendant upon the foregoing total solar eclipse with those observed by Mr. J. R. Hind, of the Observatory, Regent's Park, who has recorded some careful observations, made by him at Ravelsburg, near Engelholm, on the west coast of Sweden, within the limits of the shadow, whither he proceeded to await the total eclipse of July 28, 1851. Beyond the scenic effects resulting from this eclipse, Mr. Hind describes the appearance of red flames and projections from the sun's limb—the beads produced by the edges of the moon—and the corona, or halo of glory, exhibited during actual totality. The *first* are supposed to be due to certain gaseous influences operating in the luminous atmosphere of the sun; the *second* are small bright spaces on the edge of the sun's disk, just before and after totality, caused by the sun shining between the mountain-peaks and conical hills, and along the valleys, on the apparent edge of the moon; and the *third*, which has not yet been well accounted for, seems to be a natural result of light being suddenly and totally intercepted in its direct passage, and additionally diffused all around.

LECTURE XIII.

THE TIDES, SPRING AND NEAP—LOCAL PECULIARITIES—AERIAL TIDES.

We are now arrived at the proper place for explaining the phenomenon of tides. A multitude of hypotheses have been suggested respecting these regular and periodical fluctuations of the ocean; and though their relation to the moon had been remarked in the remotest antiquity, it was Kepler who first demonstrated their dependence upon the attraction of that body. Newton then showed that this opinion is in harmony with the laws of gravitation; and deducing its legitimate consequences from the principle laid down by Kepler, he explained how the tides occur on the two sides of the earth opposite to the moon. This theory is now beyond all dispute.

The waters of the ocean possess a mobility which makes them yield to the slightest impressions: the ocean is open on all sides, and the great seas communicate with each other: these circumstances contribute to the formation of tides, which owe their existence principally to the joint action of the sun and moon.

Let us first consider the action of the moon. It is evidently the inequality of this action which produces the tides; nor would there be any, if the moon acted equally on the whole extent of the ocean, that is, if it exerted equal and parallel forces on the centre of gravity of the earth, and on all the molecules of the waters; for then the entire system of the globe being actuated by a common movement, the equilibrium would be preserved. This equilibrium, then, is only disturbed by the inequality and the want of parallelism in the moon's attractions. We can readily conceive how her action, oblique with respect to those molecules of the sea which are in quadrature with her, and direct with respect to those which are exactly under her, renders the former weightier, the latter lighter. In order, therefore, that the equilibrium be re-established, the waters must rise beneath the moon, so that the difference in weight may be compensated by a greater depth. The molecules of the ocean situated in the corresponding point of the opposite hemisphere, less attracted by the moon than is the centre of the earth, in consequence of their greater distance, will be less disposed to move towards the moon than it; the centre of the earth, therefore, will have a tendency to recede from the molecules, which, in consequence, will be situated at a greater distance from this centre, and will be furthermore sustained at this height by the superior weight of the molecules at the quadratures, which communicate with them.

To make this obvious by a figure, let ABCDE FGH be the earth, and M the moon. Attraction operating inversely as the squares of the distances, the waters situated at Z will be more strongly attracted than those at B and F; the waters at Z must, therefore, rise. On the other hand, the centre of the earth, O, being nearer the moon than the waters at N, will be more powerfully attracted than they; it will therefore approach more to the moon, or, in other words, will recede from the waters at N, which will be sustained by the weightier molecules at the quadratures; we say *weightier*, because the oblique attraction of the moon becomes decomposed, and increases their gravity. In fact, the waters situated at B and F, drawn by this oblique force, tend to approach towards O. Hence it follows, that there will be formed on the surface of the earth two menisci of waters, the one on the same

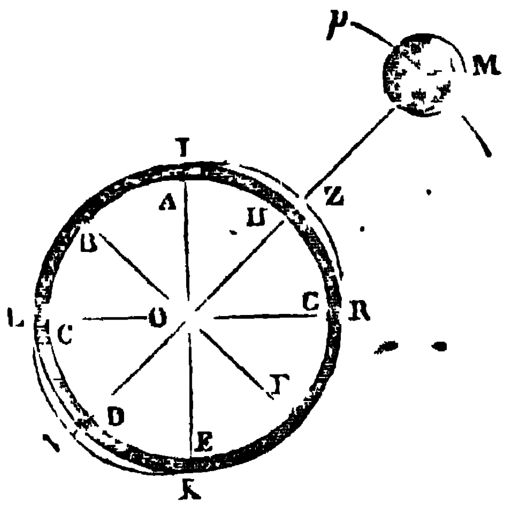

Fig. 30.

side as the moon at Z, the other on the opposite side at N, which will give the earth the appearance of an elongated spheroid, the greater axis of which will pass through the centres of the earth and moon. Hence, we see that there would be in each place only two elevations of the waters in a month, were it not for the earth's diurnal rotation. Let us see how this complicates the phenomenon.

By the earth's rotation on its axis, the more elevated part of the water is carried away from the moon in the direction of the rotation; but the water still obeys the attraction it has received, and continues to rise after it has quitted its position directly under the moon, though the immediate action of that planet upon it be no longer as strong as it was. The water does not thus attain its utmost elevation till after the moon has ceased to be at the meridian of its position. In open seas, where the waters flow freely, the moon is at *p* when the highest waters are at Z and at N. It is easy to conceive, that, though the planet's attraction were to cease immediately after its quitting the meridian, still the ascending movement given to the waters would continue to accumulate them for some time; much more must this effect take place when the attraction only suffers diminution.

Again when the moon raises the waters at Z and N, it lowers them at B and F; for they cannot rise in one place without falling in another; and, reciprocally, it depresses them at N and Z when it elevates them at F and B; but by reason of the earth's rotation, the moon passes every day the superior and the inferior meridian of each place, and will, therefore, produce in it two elevations and two depressions of the waters, as is actually the case.

Hitherto we have considered only the isolated action of the moon. Let us see how that of the sun is combined with hers.

The attractive force exercised by the sun upon the earth is much greater than that manifested by the moon; but as the distance of the former body is nearly four hundred times greater than that of the second, the forces exerted by the one upon the different parts of our planet approach much nearer to parallelism, and consequently to equality, than those of the other. And, inasmuch as it is only the inequality of the moon's action that produces the tides, the much more equable motion of the sun must be less adapted to produce the same effect. Its influence in this respect has been calculated as about two and a half times feebler than the moon's. Still it is sufficiently energetic to produce a flux and reflux; so that there are, in reality, two tides, one lunar and the other solar, the effects of which augment or weaken each other, according to the direction of the forces producing them. Thus, when the moon is new, as at A, or full, as at B, that is to say, at the syzygies, these two bodies are in the same meridian, their efforts concur, and the effect must be the greatest possible. When, on the contrary, the moon is in quadrature, it tends to raise the waters which the sun tends to lower, and reciprocally, so that the efforts of

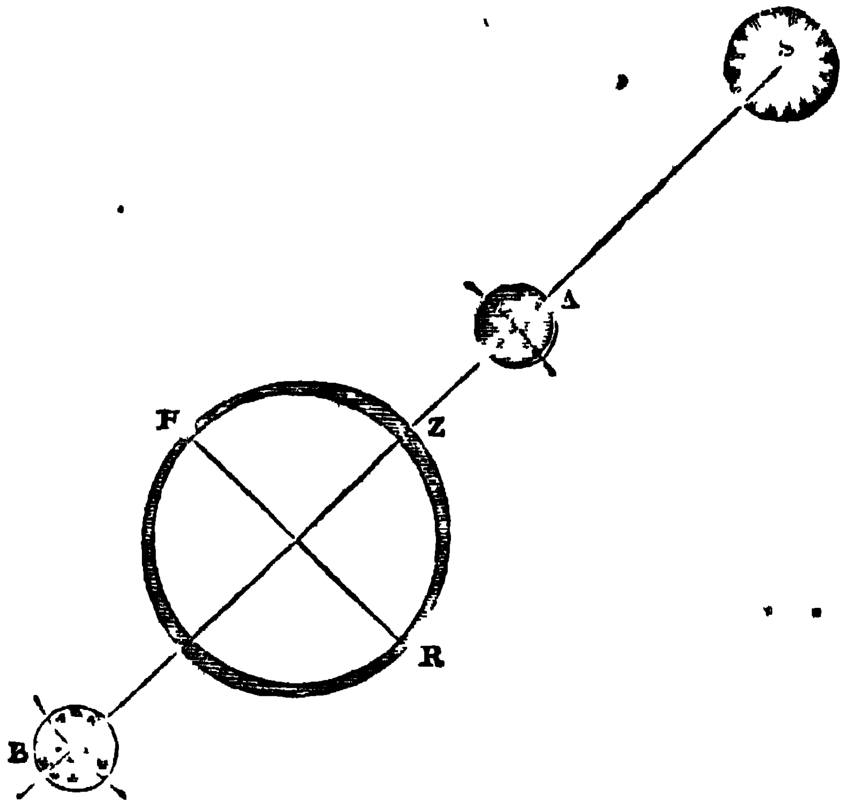

Fig 31.

these two bodies combating each other, the effect must be the least possible. The former are called *spring* tides, the latter *neap* tides. At Q the moon is in the first quarter, or 90° E. from the sun: at R the moon is in the last quarter, or 90° W. from the sun.

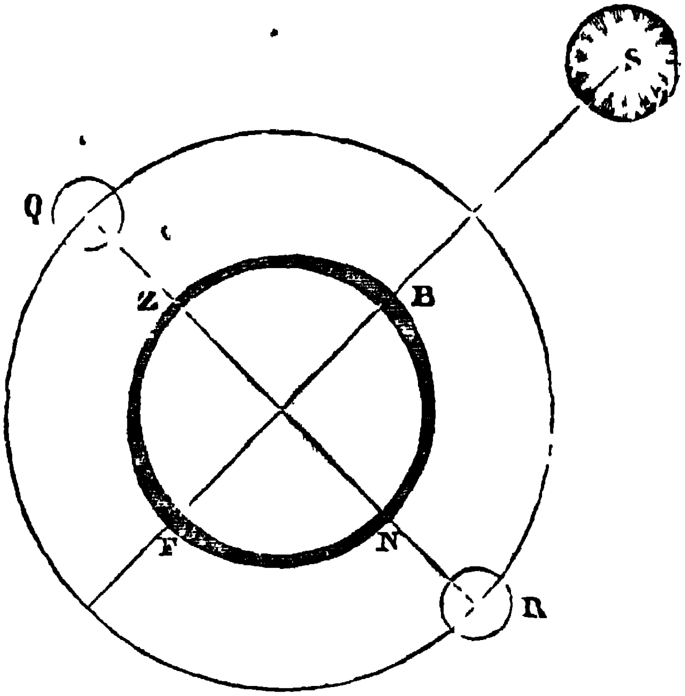

Fig. 32.

It would seem to follow from this, that the tide should be full at the instant when the force resulting from the attractions of the sun and moon is arrived at its greatest intensity; but we have already seen that it is not so. In fact, on the days of full moon, when the two bodies exercise their attraction in one and the same direction, the moment of the greatest intensity of that action is that of their simultaneous passage of the meridian, or of noon, yet the tide is seldom full till some time after noon. Experience has shown that the tide which occurs on the days of new moon, is that which has been produced thirty-six hours previously by the action of the sun and moon; it has been remarked, besides, that at this epoch high water always arrives at the same hour. Hence it has been concluded, that the interval of time at which the moment of high water follows that when the two bodies exert the greatest influence, is constantly the same. The second consequence that has been drawn from these two facts is, that the action of the sun and moon is felt in ports and on the coasts, by way of successive communication through waves and currents. We have said that, on the days of new and full moon, the instant when the two bodies exert their greatest force is that of the passage of the sun and moon across the meridian; the same is the case in the first and the last quarter. On other days, this instant sometimes precedes the passage, at other times follows it, but it is never far distant from it; because, as we have seen, the attractive force of the moon is much greater than that of the sun. These forces, and the tide's slowness or fastness relatively to the moon's meridian-transit, vary accordingly as the two bodies recede from, or approach the earth,—as their declinations augment or diminish. The floods are higher, and the ebbs lower, at the equinoxes in March and September, because then all the circumstances that influence the elevation of the waters concur to produce their most powerful effect.

The following are the principal circumstances of the phenomena of tides. The sea flows about six hours from south to north, swelling by degrees; it remains about a quarter of an hour stationary, and then retires from north to south during other six hours. After a second repose of a quarter of an hour, it begins to flow again, and so on.

The mean duration of the ebb and flow is about $12^h\ 25'$; that is, half the lunar day of $24^h\ 50'$, the period elapsing between successive returns of the moon to the same point of the meridian. Thus the sea in every place undergoes a flux and reflux as often as the moon passes the meridian, whether superior or inferior, of the place; that is to say, twice in $24^h\ 50'$.

These laws of ebb and flow would be perfectly in accordance with the phenomena, if the waters of the sea covered the whole face of the globe: it is not so, and it is scarcely anywhere but in the open seas that they appear exactly as we have described them; because the ocean is of sufficient extent to allow of the action of the sun and moon taking place upon it freely. But these phenomena are necessarily modified in the neighbourhood of the shores by the direction of the winds, the situation of the coasts, and a number of local accidents.

Tides make themselves felt in large rivers, the waters of which they drive back: they are sometimes felt more than 500 miles from the mouth.

Lakes have no tides, because they are too small to allow of the moon's action being unequally exerted upon them. Besides, she passes so rapidly over their surface, that there is not time enough to allow of the equilibrium being disturbed.

Neither are there tides in the Mediterranean, nor in the Baltic, because the openings by which these great gulfs communicate with the ocean are so narrow, that they cannot in so short a space of time receive a sufficient quantity of water to allow of their level being sensibly elevated.

In the West India islands, the tides are very low: they seldom rise above twelve or fifteen inches. The anomaly may perhaps appear the more remarkable, as these latitudes, adjoining the equator, must be subjected to a very energetic force of attraction. But it will be readily conceived, that the water cannot fluctuate much in the neighbourhood of these islands, if we reflect, that the earth turning from west to east, the flow of the tide takes place in the opposite direction, and breaks like a vast wave upon the coast of America, which stops it, and prevents its passing with the moon towards the Pacific Ocean. The winds, besides, which blow continually from east to west, are opposed to the ebb from the east.

These same two causes produce a very remarkable effect in the Gulf of Mexico. The winds and the tides continually impel the waters into this great cavity, where they accumulate them above the general level, and by their incessant action prevent them from falling back again as they came. Thus suspended, and unable to overcome the forces that resist their return, these waters flow round the west coast of Cuba, take a northern direction towards the coast of America, and form the very remarkable current of the Gulf of the Floridas. So true is it that the waters accumulate in the Gulf of Mexico, that it has been found, by effecting a series of levelling operations across the Isthmus of Panama, that they rise fourteen feet higher than in the Pacific Ocean.

Since the air is endowed with lightness and mobility in a still higher degree than the waters, it must also obey the combined action of the sun and moon; and there must be atmospheric tides. At first sight, however, a fact seems to militate against this conclusion, namely, that the barometer does not indicate these successive elevations and depressions in the atmosphere. But then it is evident the barometer ought to remain insensible to these variations; for the columns of air, though of different heights, must everywhere be of the same weight, since the direct effect of the tides is, as we have seen, to maintain the equilibrium of the fluid, by compensating by height for the diminution of weight.

LECTURE XIV.

LATITUDE AND LONGITUDE.

To determine the position of a point on any surface, it is necessary to know the point's distance from two fixed lines on the surface: these two lines may be differently arranged, but their situation on the surface once fixed, it must remain invariable. For the greater facility, however, in calculation and construction, instead of giving these lines an indefinite inclination, they are arranged so as to form a right angle with each other. Thus the proceeding, which will enable us to fix the positions of the different points on the earth's surface, is absolutely the same as that we employed to determine the positions of the stars. All we need in fact is, to know the parallel in which is situated the point whose position we wish to fix, and its place in that parallel, which are, in other words, the latitude and longitude of the point.

Now the latitude is found by taking the elevation of the pole above the horizon; for it is always equal to that elevation. Suppose the point C to be distant, say thirty degrees from the equator towards the arctic pole, its zenith will be in CF, the great circle HOR will be its horizon; the plane of the equator EOZ will be distant thirty degrees from the zenith F, and consequently 60 degrees from the horizon; the pole P will be elevated thirty degrees, measured by the angle HCP.

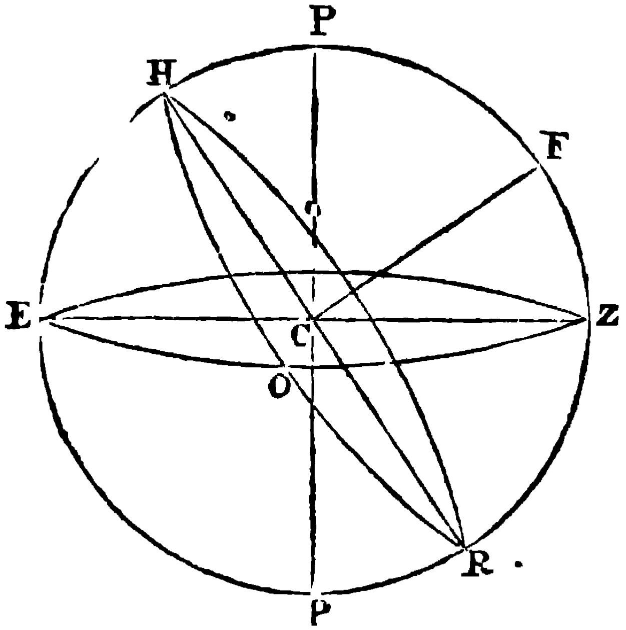

Fig. 33.

But as there is, in the other hemisphere, a circle presenting the same conditions, we must state whether the latitude is northern or southern. The determination of the longitude presents more difficulty: to obtain it, we measure, in degrees of the equator, the distance separating the meridian of the place from another given meridian; and this distance may always be ascertained, provided we know the hour at the place where the observation is made, and that of the place whose meridian is taken as the standard of comparison. For, since every place on the earth's surface, by reason of its rotation, describes a circle, or 360 degrees, in twenty-four hours, it describes fifteen degrees in an hour, fifteen being the twenty-fourth part of 360 degrees. When, therefore, two places are separated by fifteen degrees of longitude, the sun does not appear in the meridian of the more western, till one hour after it has appeared in that of the other; and the latter counts twelve hours, when the other only reckons eleven hours in the morning. If the distance separating the two places is thirty degrees, the difference is two hours, and so on. Thus, the difference of time being given, nothing is more easy than to find the difference of longitude, and *vice versâ.*

The whole difficulty then resolves itself into that of knowing the difference of time: a multitude of ways are employed to get at this. As it would be impossible for us to describe them all here, we shall confine ourselves to a few amongst them.

The exact times at which eclipses of the moon and of the sun, occultations of stars by the moon, eclipses of Jupiter's satellites, &c., occur at a given meridian, are announced several years beforehand. Let us suppose that a traveller, placed at any distance whatever east or west of the meridian, observes one of these eclipses or occultations: on recurring to his tables, he will find what the time is at the given meridian; and the difference between this time and that of the place where he is situated, will give him the longitude of that place. Observations of this kind may be made as often as the weather is clear, the phenomena which give rise to them being much more numerous than the days of the year; nor are very powerful instruments even requisite for this purpose: at sea, however, some difficulty arises from the rolling of the vessel.

Marine watches, or chronometers, are of great assistance in determining longitude. Similar in construction to ordinary watches, they are only fitted up with extreme care, and are furnished with a compensator, so that they preserve the utmost regularity in their movements, in spite of the variations of temperature, and the inevitable shocks they must sustain in a long voyage. The chronometer is regulated at the moment of departure, and set exactly to the time of the meridian, to which the longitude is to be referred. By these means the mariner has always the difference of time, and consequently of longitude, since he can always, by taking the time of the place he is in, compare it with that of the first meridian given by the chronometer.

We see that this method of solving the important problem of longitude is so easy and simple, that it would be useless ever to have recourse to any other, if we could always reckon securely on the correctness of the chronometer. Unfortunately, this is not always the case. Modern skill, however, has brought these instruments to a degree of perfection that could hardly have been anticipated or hoped for. An idea of this may be formed from the following extract from the Elements of Natural Philosophy :—"Let it be allowed the author of this book to make his readers acquainted with the surprise and pleasure he experienced, after a long passage from South America to Asia. His pocket-chronometer, and those belonging to the ship, announced one morning that a tongue of land marked on the chart, should bear fifty miles east of the vessel. Imagine the delight of the crew when an hour afterwards, the morning fog having cleared off, the man on the look-out uttered the joyful cry, Land! land ahead! thus confirming the prediction of the chronometers to within a mile. At a moment like this, one may well be struck with deep admiration of the genius of man. Compare the dangers of ancient navigation with the confident course of our vessels, and then deny who can, the immense advantages of modern art! Had the action of a little instrument been in the minutest degree disturbed during a space of some months, its prediction would have been more pernicious than useful; but by day and by night, in calm and in storm, in heat and in cold, its pulsations followed each other with imperturbable uniformity, keeping, so to speak, an exact account of the motions of the heavens and the earth, and amidst the waves of the ocean, on which the keel prints no track, it always marked the position of the ship whose safety was confided to it, the distance it had traversed, and that which it had yet to run."

The meridian to which each astronomer refers his observations is entirely arbitrary, and varies in every nation. For a long while it was the general custom to take as the first meridian that of the island of Ferro, the most western of the Canaries; but this custom has gradually fallen into disuse, and each people now reckons from that which passes through its own capital.

LECTURE XV.

THE ATMOSPHERE—MOON IN THE HORIZON—THE HARVEST-MOON.

The Atmosphere.

THE atmosphere is that gaseous covering that enwraps our globe. Before inquiring into the influence it exercises upon the observation of astronomical phenomena, we shall do well to dwell for a moment on the examination of some of its properties.

And in the first place, what is the height of the atmosphere? This question is solved by the aid of one of the most valuable instruments known to physics; namely the barometer, whose use is to indicate the *weight* of the atmosphere. It is obvious that, if we carry the barometer successively to different heights, it must manifest differences in the weights of the columns of air at the different stations, and a simple proportion would then enable us to obtain the absolute height of the atmospheric stratum, if it were of the same density throughout. But gases being extremely compressible, the lower strata, which have to sustain the weight of all those above them, are necessarily more compressed, and the density of the atmospheric column must continually diminish from the surface of the earth up to the highest strata. To obtain, therefore, equal diminutions in the column of mercury, we must, as we ascend, traverse distances the greater in proportion as we mount higher. It has been proved by calculation, that, supposing the temperature of the air everywhere the same, the heights of the mercury diminish in arithmetical progression, whilst the elevations above the level of the sea increase in geometrical progression. But in operating with the barometer, we must make due allowance for the temperature, and for the hygrometrical condition of the different strata of the atmosphere. Its mean height has been estimated in this way at from forty-four to forty-seven miles, its volume as the twenty-ninth of that of the globe, and its weight only forty-three thousandths.

But what is there beyond the atmosphere? Is there any fluid, or only an absolute vacuum? Really, we are at a loss to conceive how it is this question so long engaged the attention of scientific men; for, in point of fact, there is no question admissible in the matter. In addition to what we have already stated respecting all-pervading *ether*, when speaking of comets, p. 120, how can the celestial spaces be void when they are filled with light? Surely, whatever opinion be adopted respecting the nature of this agent, whether it be a real emanation from the substance of luminous bodies, or a fluid put in motion by them, it is very evident that, upon either hypothesis, an absolute vacuum cannot exist.

It is particularly in relation to its action on the luminous rays which traverse it, that the atmosphere bespeaks our attention.

We have seen before, page 5 and 6, the modifications that light experiences in passing from one medium to another; how it is refracted, and how its rays are decomposed.

To this property we owe the various shades that colour the horizon at the rising and the setting of the sun. It is owing to it, too, that we do not pass abruptly from day to night, but are led gradually and with an easy transition, from the one to the other, by twilight and dawn. These two phenomena vary with the season and the place. It is calculated, that in our latitude, day does not cease entirely till the sun is sunk eighteen degrees below the horizon.

One of the effects of atmospheric refraction is to alter the apparent positions of the stars. The several strata of the atmosphere, increasing in density as they approach the surface of the earth, may be considered with respect to each other as different media. The rays of light that traverse them bend therefore more and more, as they pass from the one to the other; and, as the increase of density takes place by insensible degrees, the ray of light, instead of shaping its course in a series of broken lines, takes a curved direction, the concavity of which is turned towards the earth's surface. It will be perceived without difficulty, how the effect of this refraction is to make objects appear above their real position; for, since we always refer objects to a place in the straight line of direction of the ray at the moment it enters the eye, we see them in this case in the prolongation of the tangent to the curve at the point where it enters the eye. Thus it is that refraction augments the apparent elevation of the stars.

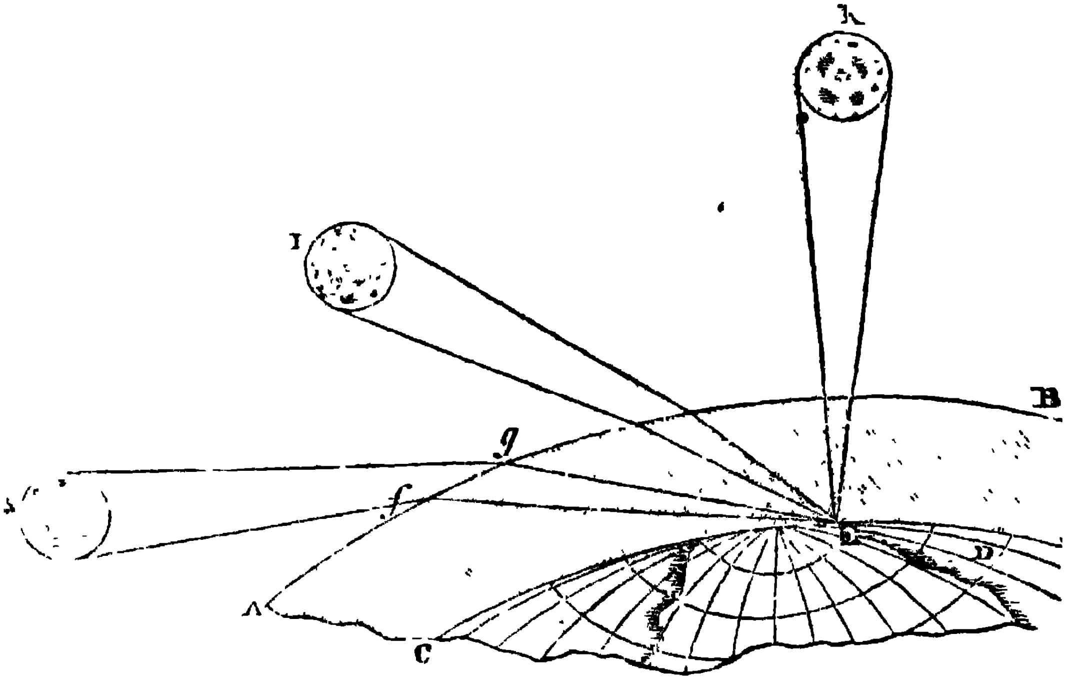

Fig. 34.

In the foregoing figure, the atmosphere AC, BD, envelops the earth CED. H, I, or K, represents the moon, for instance, at H in the horizon, at K in the zenith, and at I at an intermediate position. Now it will be observed that the angle of refraction fEg is greatest at the horizon, smaller at I, and nothing at the zenith; in other words, that the distortion of the rays of light from the moon, on entering the atmosphere, is greatest at H, less at I, and nothing at K. Hence, a heavenly body is seen in its true place only in the zenith. This may be illustrated by putting a stick into water: if inserted perpendicularly, no distortion is visible; but, the more the stick is slanted, the more bent it appears, and the most so as it tends to coincide with the horizon.

Of the Moon in the Horizon.

This is the proper place for explaining a phenomenon exhibited by the moon in the horizon: in that situation, the planet exhibits an elliptical form, and appears much larger and less brilliant than when it is in the meridian.

To begin with the more easily explained circumstance: it is plain that if the brilliancy of the moon is less vivid in the horizon than in the meridian, it is because the rays it sends us have to traverse a much thicker and denser atmospheric stratum in the former than in the latter position, as appears from the last figure at fE. It is not surprising, therefore, that these rays should be weaker and more discoloured, especially if we reflect that, in slanting along the earth's surface, they have to pass through a great quantity of vapour.

As for the apparent dimensions of the moon's disk, this is a phenomenon that has been much discussed by natural philosophers. What can be the cause of this phenomenon, since the moon is actually more distant from us in the horizon than in the zenith, by the entire semi-diameter of the earth; a difference, however, to say the truth, so small, that it cannot produce any sensible effect on the apparent diameter of the planet? Gassendi thought that as the moon is less brilliant in the horizon than in the zenith, we open the pupil wider on looking at it in the former station, and that it is for this reason we see it larger. But that this conclusion should be valid, it would be necessary that variations in the openings of the pupil should produce variations in the dimensions of the image on the retina. Now this notion, wholly at variance with the principles of Optics, is confuted by the most accurate experiments. Others have supposed, perhaps with more reason, that the moon's apparent increase of size in the horizon is owing to our supposing her more distant. For, say they, two things are involved in the act of vision, the angle under which we see objects, and the distance at which we suppose them to be. This appreciation, which, unknown to ourselves, we make of distance, tends to correct the impression produced by the image; and so true is this, that we can form a very just judgment of the height of two men, for instance, though they are at very unequal distances, and consequently present themselves under very dissimilar angles. Another experiment is striking. If we place an object in a horizontal plane, and setting the eye in the prolongation of this plane, then look at the object so as to see two images (which will be the case if we press the lower eyelid slightly with the fingers), the two images will be of different dimensions; the nearer one will be smaller than the other, and that in proportion as it approaches nearer to the eye. What proves that the difference in the distances of the images alone causes the difference of their apparent dimensions is, that, if the experiment be made so as to have the images on a vertical plane, it will be to no purpose that we separate them; they will always appear the one as large as the other. Now, continue the advocates of this mode of explanation, the moon in the horizon appears to us to occupy the lower portion of a dome; it therefore seems to us more distant than when it is in the summit of the dome, that is, in the zenith. Besides, in the former situation, its apparent distance is further increased by the comparison afforded by intermediate objects. Thus the erroneous judgment formed of the distance, modifies the impression produced by the image, and makes the moon appear greater than it ought to be.

Such is the explanation generally given in the present day. But without contesting the principle on which it reposes, we think that, if the cause assigned concurs to produce the phenomenon in question, it is not the only one, and that there is another, the action and effects of which are much more evident, namely, refraction. In fact, the rays proceeding from the extremities of the moon's disk, reach the eye at an angle enlarged by the refraction the atmosphere has made them undergo with respect to each other: the planet thus seen, subtending a more open angle in consequence of refraction, must therefore appear larger.

As to the figure it assumes, this again is a result of refraction. The moon, we have said, assumes an elliptical form, that is to say, its vertical is smaller than its horizontal diameter. This should be so; for the rays proceeding from the extremities of the horizontal diameter penetrating the atmosphere at the same angle are equally bent, but this is not the case with the rays issuing from the extremities of the vertical diameter: those of the lower extremity, entering the atmosphere more obliquely than those issuing from the upper, are more refracted, and consequently make the parts of the disk from which they are given out appear proportionally too high. This inequality of refraction must, therefore, alter the moon's figure.

The Harvest-Moon.

As we are on the subject of the moon, we will say a word about two other phenomena it presents. Twice a year it rises almost at the same hour during a week. It then takes the name of the Harvest-moon, and also of the Hunter's moon.

The moon, as we have seen, moves in its orbit from west to east. When, therefore, the earth, in consequence of its diurnal motion, returns from a meridian back again to the same, the moon, which has travelled in the same direction rather more than a thirtieth of her orbit, is further advanced by about 12° 11′; at least such is the fact when she is in the equator or its vicinity: but in high latitudes remarkable differences take place.

Since the plane of the equinoctial line is perpendicular to the axis on which the earth performs its rotation, it is evident that all parts of the equinoctial circle make equal angles with the horizon both eastward and westward, and that in equal times there is always an equal number of these parts above and below the horizon. If, then, the moon moved always on the equator, and every day gained 12° 11′ upon the sun, as she does in her orbit, she would rise and set about fifty minutes later daily.

But her orbit is far from coinciding with the plane of the equator; it approaches much more to that of the ecliptic, and for a moment we may consider them as identical. Now the different parts of this plane, which is oblique to the axis of the earth, make different angles with the horizon, whether to the east or to the west. The parts which rise with the smallest angles are those which set with the largest, and *vice versâ*. In equal times a larger portion of the ecliptic rises when this angle is smaller than when it is larger. Thus, let L be the latitude of London, AB its horizon, FP the axis of the earth, E*e* the equator, K*k* the ecliptic. The ecliptic, in consequence of the oblique position of the sphere, is considerably elevated above the horizon of London, and makes, in fig. 35, the angle AVK, of about sixty-two degrees and a half, when the sign of Cancer is in the meridian, whilst Libra is rising in the east. But when the other part of the ecliptic is above the horizon, that is, when the sign of Capricorn is in the meridian, and Aries is rising in the east, the ecliptic makes but a very small angle with the horizon, *k* VA, fig. 36,

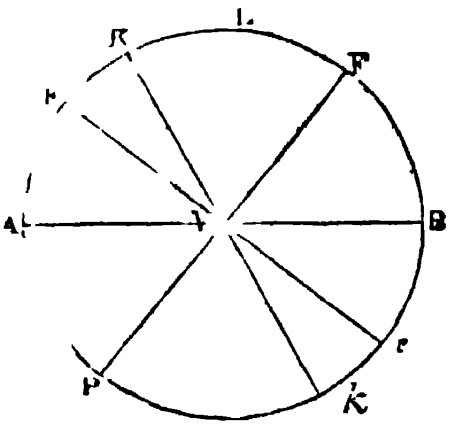

Fig. 35.

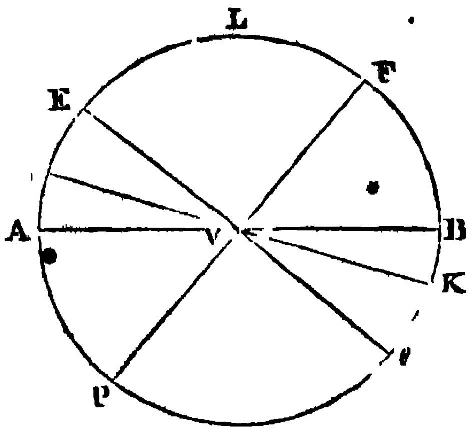

Fig. 36.

of about fifteen degrees, that is, forty-seven degrees and a half less than the former.

Thus, the celestial sphere appearing to turn round the axis F P, a greater part of the ecliptic will rise in a given time when it is in the position in fig. 35, than when it is in that shown in fig. 36.

In northern latitudes, it is when Aries is rising and Libra is setting, that the ecliptic appears to make the smallest angle with the horizon; it makes the greatest angle, on the contrary, when Libra rises and Aries sets. From the rising of Aries to that of Libra, a space equivalent to twelve sidereal hours, the angle augments; it diminishes from the setting of the one to that of the other. Thus the ecliptic rises more rapidly towards Aries, and more slowly towards Libra.

But in the parallel of London, the ecliptic rises as much towards Pisces and Aries in two hours, as the orbit of the moon in six; whilst she is in these signs her rising is retarded but by two hours in six days, that is, in the mean, by twenty minutes daily: but the moon enters, fourteen days afterwards, into the signs of Virgo and Libra, which are opposed to those of Pisces and Aries; and whilst she is in these signs, her risings are daily later by about $1^h\ 15'$. As Taurus, Gemini, Cancer, Leo, Virgo, and Libra, come in succession, the angle formed by the ecliptic with the horizon augments when they rise, and diminishes when they set. Thus, the risings of the moon are more and more retarded whilst she is in these signs, and the case is the reverse with her settings; then the difference in the risings diminishes from day to day in the six other signs, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces, Aries.

But the moon makes the circuit of the ecliptic in twenty-seven days eight hours, and takes twenty-nine days and a half to return to the same point; so that in each lunation she is at least once, and sometimes twice, in Pisces and Aries.

Were it not that the sun appears to move in the ecliptic in consequence of the earth's change of place, each new moon would fall upon the same sign, and each full moon upon the opposite one; since in the interval the moon would precisely make the circuit of the ecliptic: but as the full moon rises exactly when the sun sets, because when one point of the ecliptic passes below the horizon, the point exactly opposite emerges above it, it would always rise in the two hours of sunset in the parallel of London during the week when it is full. But whilst it recedes, with respect to the ecliptic, from a conjunction or an opposition, the sun passes to the next sign in twenty-seven days and a half. The moon then in the same time exceeds its revolution, and advances much more than the sun can do in this interval of two days one-fifteenth, before it can return to opposition or conjunction with him. We see, therefore, that opposition or conjunction can occur only once in any one point of the ecliptic. In the same way, the two hands of the clock are never more than once in twelve hours in opposition or in conjunction in the part of the dial they have traversed.

Now, as the moon is full only when in opposition to the sun, and as the latter is in the signs of Virgo and Libra only in autumn, the moon can be full in the two opposite signs of Pisces and Aries only in these two months. There can, therefore, be but two full moons in the year which rise during a week almost at the same time as the sun sets; the former, occurring in September, is called the *Harvest-Moon;* and the latter, in the month of October, being in a similar predicament, is termed the *Hunter's Moon.*

Whenever the moon is in Pisces and Aries, it may rise almost at the same hour in every revolution of its orbit; but this phenomenon does not always attract attention when it occurs. Thus, in winter, these signs rise at noon, and the moon, which is then in quadrature, is not remarked. In spring, the sun and the moon are in these signs; conjunction occurs, and the moon is not seen. In summer, the rising of the moon in the last quarter takes place at midnight; it is therefore little noticed. It is only in autumn that the moon, at the full, by rising when the sun sets, renders this phenomenon very remarkable.

This phenomenon is as regular on the one side of the equator as on the other. In fact, in southern latitudes, the seasons are the reverse of those in northern latitudes. Thus the full moons of spring on one side of the equator, occur precisely in the signs of the full moons of autumn on the other side.

Reciprocally, in spring, the full moons present at their setting the same phenomenon as the full moons of autumn at their rising.

Hitherto, for the sake of simplicity, we have supposed the plane of the moon's orbit to coincide with that of the ecliptic, but we know that these planes make with each other an angle of upwards of 5°, intersecting each other in the direction of the line of the nodes. Now the moon passes twice, and often thrice, in the interval of these changes. In fact, as she gains almost a sign in the interval from one change to another, if she passes through a node at the epoch of change, or nearly so, she can return to it after having passed through the other before the next change. Besides, north of the ecliptic she rises sooner and sets later than if she moved in this plane; the contrary is the case to the south. But the retrograde motion of the nodes makes this difference vary. When the ascending node is in Aries, the southern half of the lunar orbit makes with the horizon an angle five degrees and a half less than that which the ecliptic makes with this plane when Aries rises in northern latitudes: for this reason, the moon rises with less differences of time in Pisces and Aries than if she moved in the plane of the ecliptic. But as the descending node in its turn arrives in Aries in nine years and one hundred and fourteen days, the angle which the moon's orbit makes with the horizon is greater by five degrees and a half; whence it follows, that a greater interval elapses between the successive risings of the moon in Pisces and Aries than if she moved in the plane of the ecliptic. Hence the phenomenon of the harvest-moon is not always equally remarkable; its intensity varies from its maximum to its minimum in a period of nine years and a half.

The full moon of winter is as much elevated above the ecliptic as is the sun in summer, and must, therefore, remain as long above the horizon; and, reciprocally, it remains no longer above the horizon in summer than the sun does in winter. It follows from this, that the polar circles, which have the sun twenty-four hours above the horizon and twenty-four hours below it, must also have a full moon, which remains twenty-four hours above, and another which remains as long below the horizon. But these two full moons are only those that occur about the tropics, all the others have a rising and a setting.

The poles have, as we shall soon see, a day of six months and a night of the same duration, that is, if we put out of consideration the modifications produced by refraction in the distribution of light and darkness. Now, as the full moon is always in opposition to the sun, she cannot be seen while the latter is above the horizon, nor except when she is in the northern half of her orbit; for when a point of the ecliptic rises, the opposite point sets. Thus, when the sun is above the horizon, the moon at the time of opposition is below the plane, it is, therefore, invisible half the year. But when the sun is sunk below the horizon, the full moon is visible to those places which he no longer illuminates. Thus the poles, which are deprived of the moon in summer, that is to say, when they have the sun, behold it again in winter, when he has quitted them. They are never, therefore, in deep darkness, since they enjoy for the most part the moon's light as a compensation for the long absence of the sun.

LECTURE XVI.

DAY AND NIGHT—THE SEASONS—TEMPERATURE—WINDS.

Days and Seasons.

We have already seen that if the axis on which the earth turns were perpendicular to the plane of the ecliptic, the days and nights would be of equal duration in all parts of the globe; but the inclination of the planes of the equator and of the ecliptic is 23° 28′, and this it is that produces the diversity of the seasons and of the days.

And, in the first place, it is easy to comprehend the variety exhibited by the phenomenon of day and night at different points of the earth.

At Paris, for instance, the latitude is about forty-eight degrees. This will give, therefore, for the zenith Z, H*h* will be the horizon, P*p* the line of the poles, and ES the equator. When the sun, S, is in the plane of the equator, it will describe the circle ES, divided by the horizon H*h*, into two equal parts; it will, therefore, be as long above as below this plane, and the days will be equal to the nights. But when the sun shall have declined 23° 28′ towards the south pole, or, in other words, when he shall have attained the tropic of Capricorn, he will describe the circle S′M, divided by the horizon H*h*, into two unequal parts, the greater of which is below this plane. The nights will, therefore, be longer than the days. Lastly, when the sun shall have reached 23° 28′ of northern declination, it will be in the tropic of Cancer, and will describe the circle S″*n:* the days will then be longer than the nights.

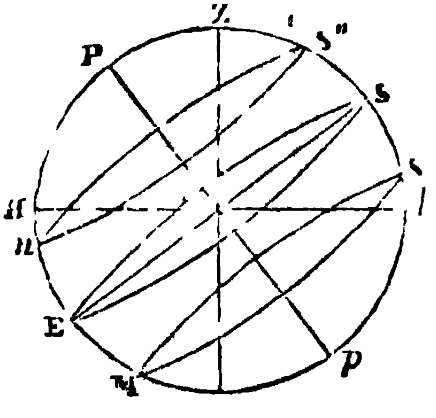

Fig. 37.

Let us now see what takes place in the equatorial regions. For there the zenith Z coincides with the equatorial plane E*e*, and the horizon H*h* with the axis of the poles P*p*. Now the sun, whether he be at S, S′, or S″, that is to say, at the equator or at either of the tropics, always describes circles which the horizon divides into

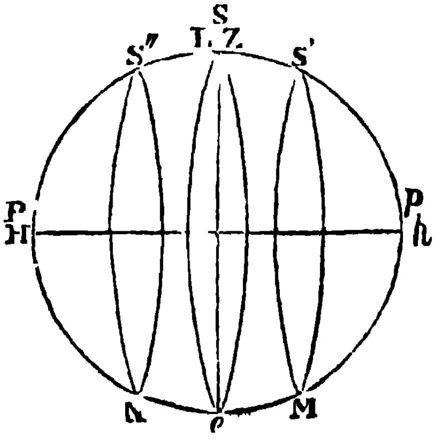

Fig. 38.

two equal parts. The equatorial regions, therefore, have always days and nights of equal duration.

The polar regions, on the contrary, have for the line of their zenith Z, which coincides with that of their poles P*p*, and their horizon H*h* becomes identified with the equator E*e*. When the sun, S, is in the plane of the equator, it describes the circle SH, which is that of the horizon, and the half of its disk is above this plane, whilst the other half is below it. But when the sun, S″, has reached the tropic of Cancer, it describes the whole circle S″N, above the horizon; whereas at the tropic of Capricorn, it describes the circle S′M, which is wholly below it. The polar regions, therefore, have the sun six months above and six months below the horizon, that is, a day and a night each of six months. Still they are not plunged in profound darkness during the absence of the sun; for we have already seen that, independently of the twilight which they enjoy till the sun is sunk eighteen degrees below the horizon, the moon too gives them light in the absence of the greater luminary. We may add, that twilight must be more intense here than elsewhere; the rapid diminution in the density of the air at small elevations, on account of the habitual congelation of the earth's surface, is one of the causes assigned as necessarily producing extraordinary degrees of refraction in these regions.

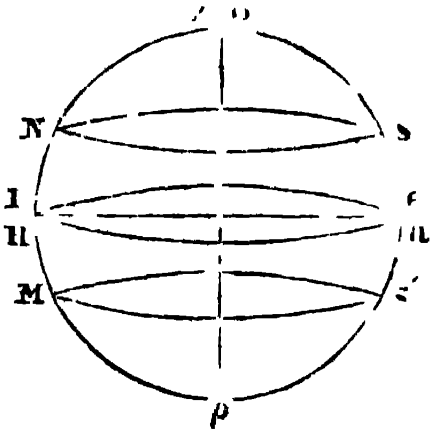

Fig. 39.

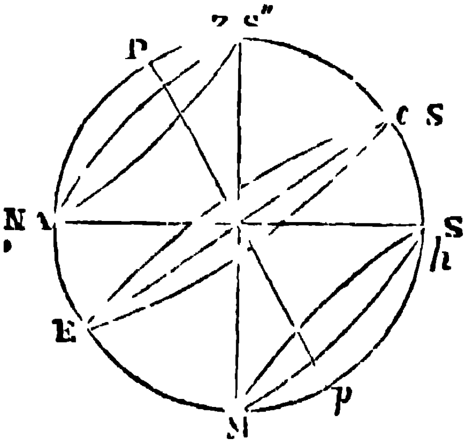

Fig. 40.

Lastly, at the polar circles the zenith Z coincides almost with the tropics. When, therefore, the sun, S, is in the plane of the equator, and describes the circle S E, divided by the equator Ec into two equal parts, the days will be as long as the nights. But when it is in the tropic of Cancer it will describe the circle S″N, and will only brush the horizon A S with its lower edge; the day will, therefore, be 24 hours long. When, on the contrary, arrived at the tropic of Capricorn, it traverses the circle S′M, it will remain 24 hours below the horizon, which it will only touch with its upper edge.

In this explanation we have supposed that the sun turns round the earth, whereas it is the earth turns round the sun; but the result is absolutely the same. To combine, however, the explanation of the real with that of the apparent phenomenon, we will make the earth turn round the sun in speaking of the seasons.

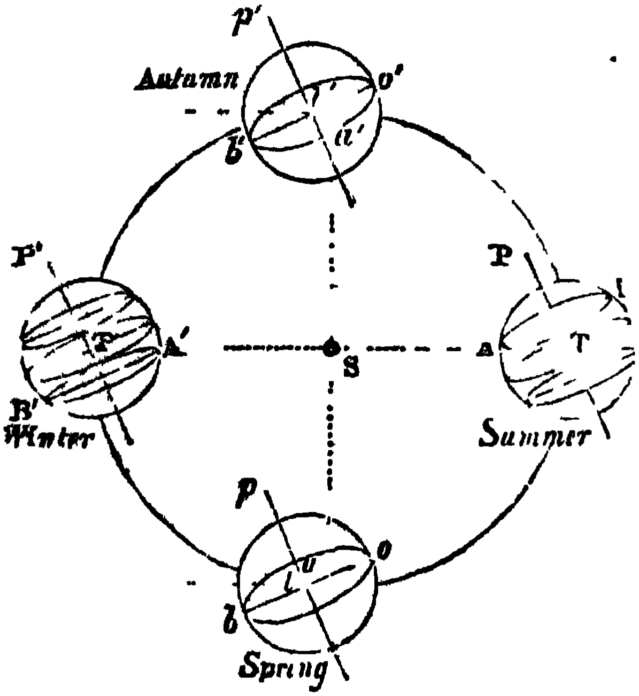

Fig. 41.

Let then S be the sun, T the earth, S T the radius connecting their centres, or the radius-vector. This radius meets the surface of the earth at A. All the points situated in the parallel A B will, therefore, have the sun successively in their zenith, as the rotary motion carries them to A, and these regions will then have summer. If the point A is the summer solstice, the parallel described by the earth's rotation will be the northern tropic; and in this position the plane PTS is perpendicular to that of the ecliptic.

But when, in consequence of the earth's change of place, it arrives at the point diametrically opposite, that is at T′, the radius-vector will meet the earth's surface at A′, and the parallel A′B′, which, in the former position, received the most oblique rays, will now receive them vertically, and the regions it includes will have summer, while those of the opposite tropic will have winter. The plane S T′P′, determined by the meeting of the radius-vector and the axis, is here likewise perpendicular to the ecliptic, as in the preceding case; but the angle STP, at which the radius-vector and the axis of the earth intersect in the former situation, is acute, whilst in this it is obtuse, S T′ P′. In the intermediate positions it is a right angle. It therefore increases from T to T′, and decreases from T′ to T.

Lastly, when the radius-vector is perpendicular to the axis of the earth at the points *t* and *t*′, and the sun appears to describe the equator, the equinoxes take place, that is, the days and nights are equal all over the earth, and it is either spring or autumn.

The space included between the tropics is called the *torrid* zone, because, the sun's rays falling there for the most part perpendicularly, the heat is excessive.

The regions which extend from the tropics to the polar circles, enjoy a moderate temperature, and are called *temperate* zones.

Lastly, the unknown regions comprised between the polar circle and the poles, constitute the *frigid* zones.

We may illustrate, by a very easy experiment, the manner in which the combined motions of the earth round its axis, and in space, produce the phenomena of days and seasons.

Take a stiff rod, of iron for instance, and bend it into a circle, as represented in the figure: seen sideways, this rod will appear an ellipse. Place in the centre a lighted candle; then fasten a silk thread to the pole of a terrestrial globe of about three inches diameter, and twist the thread, so that, when it untwists, it may make the globe turn from west to east; if you place it against the circle, you will see light and shadow succeed each other upon its surface, and imitate the regular succession of day and night. But, whilst the globe turns, if it be made to pass along the circumference of the circle, its centre being always in the plane of this circumference *bcd*, the candle, which is perpendicular to the equator, illuminates the globe from one pole to the other, as at G and E, and every part of it is alternately light and dark, making a perpetual equinox. Thus we should always have days and nights of equal duration, without variation of seasons, if the axis of the earth was perpendicular to its orbit. But this is not the case. Let us, therefore, incline the circle on which the globe turns, to the latter's axis, in the direction ABCD for instance. If we place the globe in the lowest part of the circle at H, and make it turn upon itself and round the circle, in the direction from west to

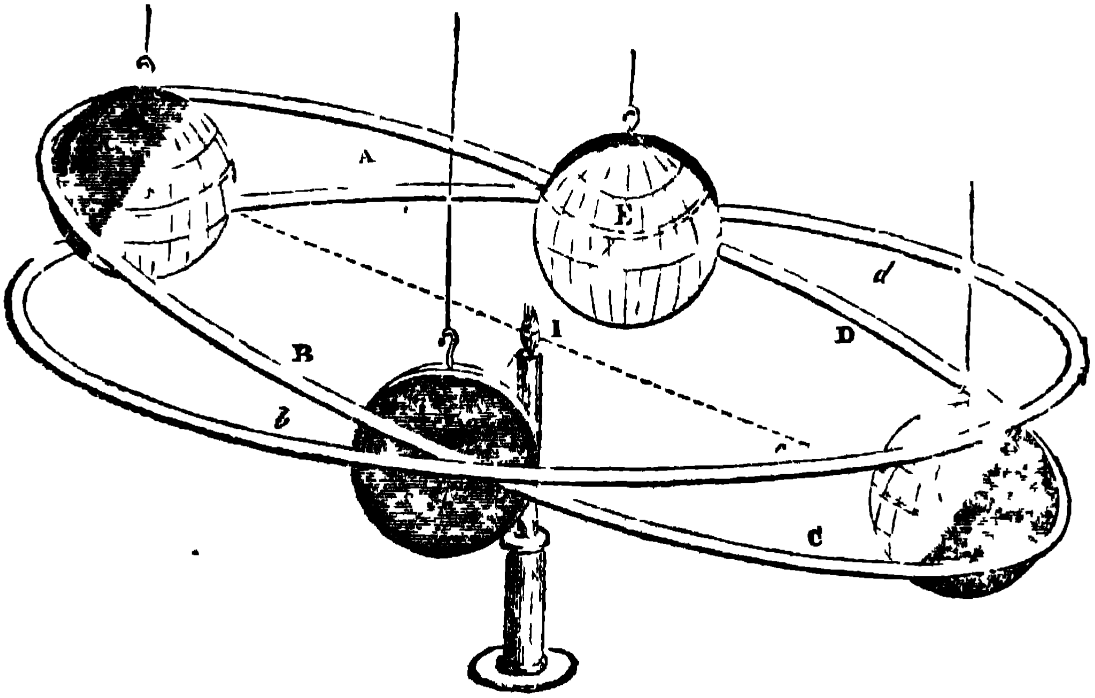

Fig. 42.

east, the candle will perpendicularly illuminate the tropic of Cancer, and the north pole will see the light. From the equator to the polar circle, the days will be longer than the nights; the contrary will be the case in the other hemisphere. The sun will not set for the northern frigid zone, or rise for the southern. But when the revolving motion shall have carried the globe from H to E, the limit of shadow will approach the northern, and recede from the southern pole: the places adjoining the former will be less and less illuminated, and the contrary will be the case with the latter. The days, therefore, decrease to the north, and increase to the south, as the globe moves from H to E. When it is at this point, the candle is in the plane of the equator, the limit of shadow stops exactly at the two poles, and the days are everywhere equal to the nights. Lastly, when the globe is at F and G, we see the same phenomena take place in an inverse order.

The Earth's Temperature.

The micrometer, in accordance with what we know of the position of the earth at different seasons of the year, teaches us that the sun is nearer us by one thirtieth in winter than in summer. The temperature of this latter season is, notwithstanding, much more elevated than that of the former. What are the causes of this? There are three principal ones. First, the physical constitution of the atmosphere, which varies in these two seasons. In summer the atmosphere is generally dry; but in winter it is loaded with vapours, which considerably weaken the intensity of the sun's rays. The second cause is, the obliquity of the sun's rays in winter: and we know that they are reflected in proportion to this obliquity, and that those that are reflected do not warm. Lastly, and this is the principal cause, the sun in summer remains much longer above the horizon than in winter. The night, the period when caloric is lost, is shorter in summer and the day longer. An idea may be formed of the effect capable of being produced upon the temperature by the difference between the days and nights, when we say it has been calculated, that, were the sun in summer to remain ten days below the horizon, it would be enough to freeze everything on the surface of the earth.

On an average, the temperature rises from the 5th of January to the 5th of July, and falls from the 5th of July to the 5th of January.

The mean temperature of the equator is from 27° to 28°; but it is remarked, that the southern hemisphere is much colder than the northern: the reason is, that the former is in a great part covered with water. Now we know that water does not heat so easily as the earth, a great part of the caloric incident upon it being incessantly absorbed by evaporation, freezing, and melting of ice. It has also been remarked, that the western shores of continents are much warmer than the eastern: this is an effect of the winds, and of the general position of the seas. In our countries, as in America, the westerly winds predominate; and these winds, blowing from off sea, are always mild in temperature, for the temperature of the sea is never very high nor very low; and this may easily be conceived: the mobility of the liquid mass, and its constant tendency to a state of equilibrium, never permitting a superficial layer to cool very much, comparatively with the rest. As soon as the temperature falls, its weight becoming augmented, it descends into the mass, and another layer takes its place.

Does the earth possess heat of its own, or does all it owns reach it from the sun? This latter opinion, which has been mentioned by some philosophers, can no longer make head against the facts at present known. We know that, at a certain depth, the temperature, independently of the action of the sun, remains continually invariable, and experiments have ascertained that it rises in proportion as we descend to greater depths: the law of this progression is almost a degree for every ninety feet.

Whatever be the cause of this proper temperature of the earth, whether it proceed from the primitive incandescence of our planet, or from the incessant action of calorific and electrical agents existing in nature, we can demonstrate that this temperature has not changed for at least many thousands of years. In fact, had the temperature of the earth at remote periods been either higher or lower, its volume, from the effect of dilatation or contraction, would have been greater or less. But then the motion of the moon must have varied. Now this is not the case, for the duration of the sidereal day is now exactly what it was in the most remote times.

We have seen that the temperature rises in proportion as we descend into the interior of the soil; it follows a contrary progression in proportion as we rise above the level of the sea. In the most usual condition of the atmosphere, we find that the temperature decreases equably with the increase of elevation in all climates, when we begin our reckoning from one and the same lower temperature; but the law of progression changes with the point of departure. So that in the temperate zones, for instance, according to Saussure's observations, the rate is in winter 426 feet to each degree of Fahrenheit's thermometer, and 296 in summer: there is, therefore, an elevation at which the progressive cooling reaches the term of ice; hence the existence of eternal snow on lofty mountains, and the unequal elevation of the point at which it commences in different climates. The vertical decrease of temperature varies also with the seasons, the exposure of the situation, and even the more or less transparent state of the sky.

One of the most interesting labours of the age is the important application made by Von Humboldt, of the geography of plants to the mean temperature of their places of growth. This celebrated traveller has determined in a general manner the elevation and the temperature of the zones in which each plant seems best to thrive. Every vegetable can only live within certain determined limits of temperature, and the proximity of these limits is indicated by the more or less stunted appearance of its growth. The aspect of the vegetables growing in each country presents, therefore, as it were, a sort of living thermometer, pointing out to the traveller their mean annual temperatures and their extremes.

In general, it will readily be conceived, that, in so vast and so moveable a mass as the atmosphere, the slightest causes of agitation may produce the greatest and the most durable perturbations. We see, therefore, that such effects must frequently result from the small local perturbations occurring in temperature, and that the greatest and most constant must result from the annual and diurnal motions of the earth—and also from the more or less energetic influence exerted by the sun upon the earth in the different seasons. Such are, probably, the most ordinary causes of those frequently long-enduring agitations produced in the atmosphere, which are called *winds.*

The most remarkable are those which blow regularly between the tropics, and which are called trade-winds. We borrow from the *Elémens de Philosophie Naturelle*, the very complete explanation there given of them.

If the terrestrial globe were at rest, and the sun's rays were always directed upon the same surface, the column of air situated above that surface would be heated to a high degree, and all the layers of that column would ascend successively, like oil to the surface of water, or as smoke mounts in a chimney strongly heated, whilst currents of air, or winds, would constantly flow in from all the lower parts towards the central surface. But the earth is continually in motion upon herself, and round the sun; the middle region, the equatorial belt or zone, may, therefore, be assimilated to the surface supposed in the preceding hypothesis; it is the part on which the sun has continually shed his beams in a direct manner, since the beginning of time: there ought constantly to have been, and, therefore, there always have been, currents towards this zone, some setting in from the southern part, some from the northern.' Such is the cause of those trade-winds, on which mariners count as securely as on the periodical return of the sun, in most of the situations comprised between the thirtieth degrees of northern and southern latitude.

These winds, however, do not appear to sweep the earth in the directions of the meridians, that is, they do not appear to blow from due north and due south, as is really the case : this proceeds from the earth's rotation on its axis, which taking place from west to east, gives the north winds the appearance of blowing directly from the north-east, and the south winds that of blowing directly from the south-east. These appearances may be easily understood from the following facts. When the atmosphere is perfectly calm, a horseman galloping over the plain seems to feel the wind blowing directly against his face with great force. If he gallop towards the east, and the wind blows directly from north or south, the twofold sensation he experiences is compounded into a mixed resulting sensation ; and in the first case, the wind will seem to him to be direct from the north-east, in the second, direct from the south-east. Another experiment :—Cause a sphere to revolve on a vertical axis, and let a small ball, or what is better still, a jet of water, roll from the superior pole : the ball or the water will not immediately acquire the velocity of the globe, but they will tend to descend by the shortest line from the pole to the equator of the sphere. Still the trace marked by the liquid on the surface of the sphere will not be a meridian, but an oblique line, which, were it prolonged, would not pass through the inferior pole. It is thus the rotation of the earth gives the trade-winds a direction towards the west; and it is not, as sometimes said, because the sun draws them along, that they have this direction.

We know that on the limits within which they prevail, that is to say, at about thirty degrees north and south from the situation of the sun, these winds seem to set in almost directly from the east; whereas, in proportion as we approach the central line, they strike ships more directly from north to south, and from south to north. This is owing to the fact, that on arriving at the extreme parallels, the cold air, as it acquires heat, dilates, and rises before it has acquired the rotary velocity of the zone it occupies; it moves with less rapidity than it, and the bodies placed in this zone, strike the air from west to east with the whole excess of their velocity; and the result is the same as if, the earth being motionless, the wind blew constantly on these bodies. In proportion, however, as the currents of air proceed on their way, they partake more and more of the velocity of the earth's rotation, and at last have almost completely acquired it by the time they arrive at the central line in the middle of the zone of sixty degrees; thus the wind from the east becomes less and less felt in proportion as we approach this line, at which it is much less sensible. Such would be the condition very nearly of a fluid poured on a wheel turning horizontally, which fluid should approach more and more from the centre towards the circumference. Arrived at the points adjacent to this limit of the circle, it would not yet have acquired all its velocity, but the continual rotation would at last communicate it completely to it; the fluid would then be in motion like the circumference, but it would be in a state of relative rest with respect to it. It must be understood, that we do not here take into account the influence of the centrifugal force.

Whilst the dense air of the polar regions precipitates itself towards the equator, to fill up the vacuum formed there, and thus gives rise to the trade-winds, that which the permanent action of the sun has dilated and elevated, must necessarily form a counter-current in the upper regions of the atmosphere, which will proceed in an opposite direction to dispose of its charge of heat. This actually takes place; and this phenomenon, anticipated by theory, has been confirmed by observation. Thus it has been ascertained that the summit of the Peak of Teneriffe is constantly assailed by a violent wind, blowing in a contrary direction to those trade-winds that swell the waves of the ocean at its feet. In 1812, the volcanic dust discharged from the island of Saint Vincent, passed in a thick cloud across Barbadoes, to the great astonishment of its inhabitants, and fell at more than a hundred miles' distance, after having accomplished this long journey in a direction contrary to the violent winds, from which ships can only escape by a lengthened deviation from their course. So also, in the voyage from the Cape of Good Hope to Saint Helena, the light of the sun is often for many days eclipsed by a mass of thick clouds, moving southwards at a great elevation in the atmosphere. These clouds are nothing else than watery vapours, that have risen from beneath the equator with the heated air, and which again become condensed on approaching the colder regions of the southern hemisphere.

Without the tropics, where the solar influence is much weaker, the winds are occasionally subjected to other causes, unfortunately at present but imperfectly known. Much less regular in the temperate regions, they are called *variable* winds: still we may regard as a general rule, applicable as well to the one class as to the other, what we have said of the trade-winds, viz. that the air, in passing towards the equatorial regions from the northern or southern poles, where it was at rest, must produce the effect of an easterly wind, or a wind opposed to the diurnal motion, until it has acquired the velocity of the zone over which it blows; and reciprocally, that the air heated in the equatorial regions, and elevated to the higher parts of the atmosphere, where it has acquired almost a corresponding velocity, falling back to the poles with this excess of velocity from west to east, must strike the bodies it encounters in the same direction.

These west winds, in a great number of situations without the tropics, are almost as regular as the winds in the intertropical zone; they are as well entitled as the latter to the name of trade-winds, so much do they abridge the passage from New York to Liverpool, compared with that in the opposite direction from Liverpool to New York. Thus in the northern hemisphere, the due north wind produces the effect of a north-east wind, and the due south wind becomes a south-west wind. England is exposed to these two winds three hundred days in the year. These phenomena, of course, are inverted in the southern hemisphere.

Lastly, we will conclude this meteorological digression by mentioning two other winds, which blow regularly on the coasts, and which are known by the names of *land-breeze* and *sea-breeze*.

When the sun is sunk below the horizon, the land and the water, which his presence had heated, lose their caloric by way of radiation; but the loss experienced by the surface of the land is much more rapid and more considerable, than that sustained by the surface of the water. The strata of air which rest on these two surfaces must consequently be differently cooled; and soon the air which rests upon the soil, being colder and denser than that over the sea, must precipitate itself into the place occupied by the latter. This occurrence takes place towards the end of the night, and constitutes the land-breeze.

But when the sun has reappeared above the horizon, its rays heat the surface of the soil much more rapidly than the mass of the waters, and the air that hangs over it must become much more heated and dilated than that which hangs over the sea. At the close of day, the colder and more condensed air will blow in towards the shore, and produce the sea-breeze.

LECTURE XVII.

THE CALENDAR.

A CALENDAR, so called from the Roman *Calendæ,* is a table showing the divisions of time by days, weeks, months, seasons, and years. We shall take a rapid review of the principal ones that have been employed by different nations. Among the Romans, the calends were the commencement of each month, when the priests recited, or *called over*, the festivals and ceremonies to be observed throughout the month just begun.

The opinion of the learned is, that the year of the ancient Egyptians and Persians consisted of 365 days; so that every four years they lost a day in the solar year, and after a period of 1460 years, called the *Sothiac period*, or *great Canicular year*, the civil and the solar year recommenced at the same time. The 365 days of the year composed twelve months, each of thirty days, and the five remaining days were added under the name of *epagomenæ*, or complementary days. This was the calendar adopted as a model by the French republic.

The Greeks had at first a year of 360 days, divided into twelve months of thirty days each; after a period of three years, which they called *trieteris*, they intercalated a month of thirty days, so that they had alternately a year of 360, and one of 390 days. They reckoned in this way until about the sixth century of our era. At this epoch, some progress having been made in astronomical acquirements, it was found that the moon accomplished her revolution in twenty-nine days and a half; this period was doubled to make two months, one of thirty days, the other of twenty-nine, which commenced with the new moon, or the *neomenia*. But, as the twelve months made but 354 days, the remaining eleven days and a half were added during a period of eight years, called an *octaëteris*, and formed three intercalary months of thirty days, placed in the third, the fifth, and the eighth years of this period. This manner of counting was in very good accordance with the course of the sun; but the Athenians, who made this reform, had learned from the oracle, that the year ought to be regulated by the course of the sun, and the months and the days by that of the moon. The civil year, such as they had arranged it, agreed well enough with the commands of the gods, but the second part of the injunction was not complied with. In fact, after an octaëteris, the moon had still a day and a half to accomplish her revolution. After two octaëterids, therefore, three complementary days, or *epagomenæ*, were added; and thus they found themselves in accordance with the moon, but they were no longer so with the sun.

To solve the difficulty, Meton, a celebrated astronomer, imagined a period or *cycle* of nineteen years, which conciliated the motions of the sun and moon, by embracing a finite number of revolutions of those two bodies. This period was composed of 235 lunations, viz. 228 at the rate of twelve to the year, and seven others for the eleven days, by which the solar exceeded the lunar year. The seven lunar months, of which six were of thirty days each, and the seventh of twenty-nine, were called *embolismic*, or intercalary months. This arrangement appeared so admirable to the Greeks, that, when it was proposed at the Olympic games, it was received with acclamations, and adopted by all their colonies. The calculation of it was exhibited in letters of gold in the public places for the use of the citizens: hence comes the name of the *golden number*, under which it still figures in our calendars. Meton's cycle, however, was not perfectly exact; for after seventy-six years, the calendar was found to be a day in advance of the moon's course.

The Arabic calendar, which is that of the Mahometans, is exclusively based on the course of the moon. The first day of each month always corresponds to new moon. But the years of this calendar are very vague; they run successively in a retrograde course through all the seasons of the year.

Let us pass on to the Roman calendar. Little is known of what it was before Julius Cæsar, who reformed it. To this effect, having learned from an Egyptian astronomer, that the solar year consisted of 365¼ days, he made the civil year 365 days, and added a sixth at the end of four years for the quarter of a day dropped. This fourth year, which contained 366 days, was called *bissextile*, or *double-sixth*, on account of the repetition of the sixth day of the calends of March. The months, twelve in number, consisted of thirty and thirty-one days, except that of February, which had twenty-eight in ordinary years, and twenty-nine in bissextile, owing to the repetition just stated; the sixth day of the calends of March agreeing with the 24th of February. The Romans divided their months into three epochs: the calends, which fell on the first day of the month; the nones, which were the fifth; and the ides, which arrived on the thirteenth. In the months of March, May, July, and October, the nones fell on the seventh and the ides on the fifteenth. The year fixed by this calendar was called the *Julian year*.

This year, however, was too long by eleven minutes nine seconds, an error amounting to a day in about 135 years; and the council of Nice having in 325 fixed Easter for the 21st of March, the day of the equinox, this festival, in 1582, had gone back to the 11th of the same month. To remedy this inconvenience, Pope Gregory XIII. published a bull, cutting off ten days from the year 1582, and commanding to reckon the 5th of October as the 15th. To prevent the return of a similar error, another modification was made. Up to that time, the intercalary day had regularly been added to February every four years: it was ordered that, in the space of 400 years, three bissextile years should be cut off; so that at present, the bissextile years are all those, the index of which is divisable by four; and when this is a secular year, it is necessary that the significant figures of the index, that is to say, the index of the century, should be divisible by four. Thus 1600 was bissextile, 1700 and 1800 were not so, nor will 1900 be so, but 2000 will. The error thus corrected is actually so small, that it may without inconvenience be neglected for several thousand years.

Such is the *Gregorian calendar*, or the *new style*. It is now adopted by almost all Christendom. The English did not adopt it till 1752, and their 3rd of September was carried on to the 14th, the Julian calendar presenting at that epoch an error of eleven days. At present, none follow the Julian calendar in Europe, but the Russians, and the Christians of the Greek church, whose year begins twelve days later than ours. This is the cause of the difference we perceive between our dates and theirs.

The months are divided into weeks. Amongst us the week consists of seven days; namely, Lundi, Mardi, Mercredi, Jeudi, Vendredi, Samedi, Dimanche (Sunday), names derived from those of the planets: thus Lundi is the moon's day (Luna), Mardi that of Mars, Mercredi that of Mercury, Jeudi that of Jupiter, Vendredi that of Venus, Samedi that of Saturn, and Dimanche that of the Sun, as their etymology indicates in other languages.* But what we should not have discovered, if historians had not communicated it to us, is the order in which these planets gave their names to the days of the week. The ancients classed the planets, or at least the stars which they considered as such, according to the duration of their revolution: thus Saturn, Jupiter, Mars, the Sun, Venus, Mercury, and the Moon. Now this is the way in which the names of the planets have come to be affixed to the days of the week in their present order. The first hour of Saturday, for instance, was consecrated to Saturn, who for this reason gave his name to the day: the second hour was consecrated to Jupiter, the third to Mars, the fourth to the Sun, the fifth to Venus, the sixth to Mercury, and the seventh to the Moon; then the eighth to Saturn, and so on, till the twenty-fourth hour, which, in following this course, came to be consecrated to Mars. The first hour of the following day was consecrated to the Sun, which follows next, and the day took its name: the second hour was consecrated to Venus, and so forth. By pursuing this in detail, it will be seen that each day of the week in turn took its name from the planet to which its first hour was consecrated.

It now remains for us to say some words of the terms employed in calendars; which terms are called *Common Notes.* They are the following; which we proceed briefly to explain:—

Solar Cycle.
Golden Number.
Epact.
Sunday-Letter.
Roman Indiction.
Number of Direction.
Julian Period.

---

* The French names of the week-days generally preserve more resemblance to the Roman than do the English. Our Teutonic ancestors *translated* the Roman names, substituting their own deities, as Wodin, Thor, &c., for Mercury, Jove, &c.—TRANS.

The *solar cycle* is a period of twenty-eight years, after which the days of the week return in the same order, and at the same day of the month, whilst the bissextile years follow regularly every four years. The bissextile years also recommence, at the termination of the solar cycle, the same course with respect to the days of the week on which fall those of the months. The solar cycle owes its origin to the fact that the year does not contain an exact number of weeks, since it consists of fifty-two weeks and one day. This cycle would therefore be only of seven years (since in that period the extra day of each year would make a week) if there were no bissextile years; but as there is one every four years, the cycle cannot be complete without containing seven leap-years, so that the extra day of each of these may give a week.

We have already spoken of the lunar cycle, the year of which is called the *golden number.* It is a period of nineteen years, after which the sun and the moon meet again in the same position, or nearly so; since the conjunctions, oppositions, &c., of these bodies are, within an hour and a half, the same as at the beginning of this period and on the same days of the month.

Since the solar and the lunar years do not recommence together till after nineteen years, there is in this interval an excess of the former over the latter. It is this number of days by which the solar year exceeds the lunar, that is designated by the name of *epact,* which implies something *added.*

The Dominical or Sunday-letter is one of the first seven letters of the alphabet, which letters are used to denote respectively the days of the week, and one of which letters must of course fall to the Sunday throughout the year. But, owing to leap-year, their order is every fourth year disturbed; so that the solar cycle must pass round, before the letters can fall respectively to the same days of the week. The year 1852 being leap-year, there are *two* Sunday-letters; the left hand letter is used till the end of February, and the other till the end of the year.

Roman Indiction was a period of fifteen years, appointed by the Emperor Constantine, A.D. 312, for the payment of certain taxes from the subjects of the empire.

The Number of Direction. It having been decided by an assembly of Christian bishops, at the Council of Nice, in Bithynia, of Asia Minor, A.D. 325, that Easter-day is always "the first Sunday *after* the full moon which happens upon, or next after, the 21st of March;" it follows that Easter-day cannot take place earlier than the 22nd of March, or later than the 25th of April; so that from one date to the other (both inclusive) are thirty-five days. The Number of Direction is that day of the thirty-five, on which Easter Sunday falls.

The Julian period consists of 7980 years; which is produced by the multiplication into each other of the solar cycle, the lunar cycle, and the Roman indiction; (28 × 19 × 15=7980.) This period is reckoned from 709 years before the creation of the world, when the three cycles are supposed to commence together, which circumstance cannot take place again until the lapse of the entire period, A.D. 3267.

The Roman Indiction and the Julian period are not now of practical use in the calendar; but they are still noticed. on account of the historical references that belong to them.

There was also a cycle, called the *Victorian* cycle, which was invented by Victorius of Aquitain. A.D. 463. It was called likewise the *paschal* cycle; its object being to regulate the computation of Easter. It was produced by multiplying the years in the Lunar cycle by those in the Solar (19 × 28), which gave a period of 532 years. It was in use until the Roman empire became extinct.

APPENDIX.

TABLE OF THE CONSTELLATIONS,

WITH THE NUMBER OF STARS IN EACH, AS FAR AS THOSE OF THE SIXTH MAGNITUDE.

* Thus marked are modern.

ZODIACAL CONSTELLATIONS.

NAME OF CONSTELLATION.	No. of Stars.	Principal Stars.	Magnitude.
Aries	66		
Taurus	141	Aldebaran	1
Gemini	85	Castor and Pollux	1-2
Cancer	83		
Leo with Coma Berenices	95	Regulus	1
Virgo	110	Spica Virginis	1
Libra	51	Zubenich Meli	2
Scorpio	44	Antares	1
Sagittarius	69		
Capricornus	51		
Aquarius	108	Scheat	3
Pisces	113		

NORTHERN CONSTELLATIONS.

NAME OF CONSTELLATION.	No. of Stars.	Principal Stars.	Magnitude.
Ursa Minor, the Lesser Bear	24	Pole Star	2
Ursa Major, the Great Bear	87	Dubhe	1
Perseus	59	Algenib	2
Auriga, the Waggoner	66	Capella	1
Bootes	54	Arcturus	1
Draco	80	Rastaber	3
Cepheus	35	Alderamin	3
Canes Venatici, viz., Asteria and Chara, the Greyhounds	25		
*Cor Caroli	3		
Triangulum	16		

NAME OF CONSTELLATION.	No. of Stars.	Principal Stars.	Magnitude.
*Triangulum minus	10		
*Musca	6		
*Lynx	44		
*Leo Minor	53		
*Coma Berenices	43		
*Camelopardalus	58		
*Mons Mænalus	11		
Corona Borealis	21		
Serpens	64		
*Scutum Sobieski	8		
Hercules cum Ramo et Cerbero			
Hercules or Eugonasia	113	Ras Algratha	3
Serpentarius or Ophiucus	74	Ras Alhagus	
*Taurus Poniatowski	7		
Lyra	22	Vega	1
*Vulpeculus et Anser, the Fox and Goose	37		
Sagitta	18		
Aquila, the Eagle, with Antinous	71	Altan	1
Delphinus	18		
Cygnus, the Swan	81	Dereb Adige	1
Cassiopeia, the Lady in her chair	55		
Equulus, the Horse's Head	10		
*Lacerta	16		
Pegasus	89	Markab	2
Andromeda	66	Almaac	2

SOUTHERN CONSTELLATIONS.

*Phœnix	13		
*Officina Sculptoria	12		
Eridanus	84	Achernar	1
*Hydrus, the Water snake	10		
Cetus, the Whale	97	Menkar	2
*Fornax Chemica	14		
*Horologium	12		
*Rheticulus Rhomboidalis	10		
*Xiphias Dorado, the Swordfish	7		
*Celapraxitellis	16		
Lepus	19		
*Colomba Noachi	10		
Orion	78	Betelgeuse	1

NAME OF CONSTELLATION.	No. of Stars.	Principal Stars.	Magnitude.
Argo Navis, the Ship	64	Canopus	1
Canis Major	31	Sirius	1
*Equuleus Pictorius	8		
*Monoceros	31		
Canis Minor	14	Procyon	1
*Chamæleon	10		
*Pyxis Nautica	4		
*Piscis Volans	8		
Hydra	60	Cor Hydræ	1
*Sextans	41		
*Robur Carolinum, Royal Oak	12		
*Machina Pneumatica	3		
Crater	31	Alker	3
Corvus	9	Algorab	3
*Croziers, Cruzero	6		
*Apis Musca	4		
*Apus, or Avis Indica, Bird of Paradise	11		
*Circinus, the Compass	4		
Centaurus	35		
Lupus	24		
*Quadra Euclidis	12		
*Triangulum Australe	5		
Ara, the Altar	9		
*Telescopium	9		
Corona Australis	12		
*Pavo, the Peacock	14		
*Indus	12		
*Microscopium	10		
*Octans Hadleiensis	43		
Grus, the Crane	14		
*Toucan	9		
Piscis Australis	24	Fomalhaut	1

SUMMARY.

Stars of the	CONSTELLATIONS	I.	II.	III.	IV.	V.	VI.	*mag.*
Zodiacal	12	5	16	44	120	183	646	1014
North	34	6	24	95	200	291	635	1251
South	45	9	36	84	190	221	323	863
Total	91	20	76	223	510	695	1604	3128

A TABLE EXHIBITING SEVERAL DETAILS OF THE SOLAR SYSTEM.

	Mercury ☿	Venus ♀	Earth ⊕	Mars ♂	Vesta ⚶	Juno ⚵	Ceres ⚳	Pallas ⚴	Jupiter ♃	Satur ♄	Hersc ♅	Nep. ♆	Sun ☉	Moon ☽
Mean distances from the Sun, the Earth s being 10	4	7	10	15	24	27	28	29	52	95	192	309		
Periodic times	days 87	days 224	days 365	days 686	days 1335	days 1592	days 1681	days 1681	yrs d 11 315	years 29½	years 83	164		
Times of rotation on axis	24h 5′	23h 30′	24h 0′	24h 31′					9h 56′	10h 16′			dys hrs 25 10	days 27⅓
Inclination of orbit to ecliptic	7°	3° 24′		1° 51′	7° 8′	13° 5′	10° 37′	34° 37′	1° 16′	2 30′	0° 46′	1° 47′		5° 8′
Inclination of planet s equator to its orbit		75	23 28′	29 30′					3° 5′	29°			7 10′	
Diameter, that of the Earth being 1	0 39	0 97	1	0 52					11 56	9 61	4 26	4 8	112	0 27
Volume, that of the Earth being 1	0 06	0 93	1 00	0 14					1470	887	77	110 6	1328460	0 02
Mass, that of the Earth being 1	0 16	0 9	1	0 13					329	100	17	21	351936	0 013
Density that of the Earth being 1	2 77	1 04	1	0 93					0 25	0 13	022	0 22	0 26	0 76
Diameter of the Sun seen from the planets	80′	44′	32′	21′	13′	12′	11′	11′	6′	3′	1′	2″		
Velocity in miles per second	30	23	19	15	13	12	11	11	8	6	4	3		¾

DISTANCES AND PERIODIC TIMES OF THE SATELLITES.

	JUPITER.			SATURN.		HERSCHEL.		NEPTUNE.	
	Mean distance, the semi diameter of the planet being 1.	Periods of revolution.	Masses, that of the planet being 1	Mean distance, the semi-diameter of the planet being 1.	Periods of revolution.	Mean distance, the semi-diameter of the planet being 1.	Periods of revolution.	Mean distance.	Pe of revolution.
I.	6·0485	1^{d}·7691	0 000017	3·35	0 943	13 12	5^{d} 895		
II.	9 6235	3·5512	·000025	4 30	1 370	17 02	8 707		
III.	15 3502	7 1548	·000088	5 28	1 888	19 85	10 961		
IV.	26 9983	16 6888	·000043	6 82	2 739	22 75	13 456	12	6^{d}
V.	...	...	...	9 52	4 517	45 51	38 075		
VI.	...	...	...	22 08	15 945	91 01	107 694		
VII.	...	...	...	28·00	22 50	...	...		
VIII.	...	...	...	64 36	79 380	...	...		

A Table showing the Days of the mean Year on which a Watch keeping good time ought to be an even number of minutes faster or slower than the Sun's noon.

DAYS.		Fast Minutes.	DAYS.		Fast. Minutes.	DAYS.		Slow. Minutes.	DAYS.		Fast. Minutes.	DAYS.		Slow. Minutes.	DAYS.		Slow. Minutes.
January.........	2	4	March	12	10	May	1	3	August.........	21	3	October	4	11	December ...	11	6
	4	5		16	9		15	4		25	2		7	12		13	5
	6	6		19	8		30	3		29	1		11	13		17	4
	8	7		23	7	June............	5	2	September ...	1	0		15	14		19	3
	11	8		26	6		11	1			S.		20	15		21	2
	13	9		29	5		16	0		4	1		28	16		23	1
	16	10	April............	1	4			F		7	2	November ...	16	15		25	0
	19	11		5	3		20	1		10	3		21	14			F.
	22	12		8	2		25	2		13	4		25	13		27	1
	27	13		12	1		30	3		16	5		28	12		29	2
February	1	14		16	0	July	5	4		19	6	December ...	1	11		30	3
	21	14			S.		11	5		22	7		3	10			
	28	13		20	1		22	6		24	8		6	9			
March	5	12		25	2	August.........	11	5		27	9		8	8			
	9	11					16	4		30	10		10	7			

The few following explanations may be acceptable to readers not familiar with mathematics.

Two lines meeting at a point form there an angle which is greater or less, according as the lines forming it diverge more or less from each other. This divergence may be conveniently measured by the arc of a circle, intercepted by the lines forming the angle (that is, cut off between them), the angular point being supposed to be in the centre. The opening of a carpenter's rule will afford us a practical illustration of this. If one bar be kept fixed on a board, a pencil-point attached to any part of the other bar will mark on the board a portion of a circle, the extent of which will be an exact measure of the opening of the rule, or of the angle formed at the pivot by the edges of the two bars. It will readily be perceived that the value of an angle, which is but another name for the divergence of two lines setting out from the same point, has nothing to do with the length of those lines, or with the actual dimensions of the circle assumed to measure the divergence. Whether we place the pencil-point at six inches or at twelve on the revolving bar of the rule, the proportion of the arc described to the whole circumference of its own circle will remain the same. The circumference of every circle, whatever be its actual dimensions, is usually considered as consisting of 360° (degrees), each of which is divided into 60′ (minutes), each of these again into 60″ (seconds), and so on to thirds (‴), and fourths (⁗), and fifths, if necessary, each term being the sixtieth of its predecessor. Some few authors, however, adopt the decimal system instead of this.

The angle measured by a quadrant, or fourth part of a circumference, or 90°, is called a right angle, and the lines constituting it are said to be at right angles with or perpendicular to each other. If one of them be supposed to be in a plane parallel to that of the horizon, it is said to be horizontal, and the other vertical. Thus, SO is at right angles with DD.

There are other means of expressing the relations of angles to each other, besides their direct measurement; these are derived from their relations to certain straight lines whose values are dependent upon the properties of the circle. Of these we shall only notice sines and tangents. From the point G, where OG, one of the legs of the angle SOG, cuts the circumference, a perpendicular G *b*, is let fall on the other leg OS; G*b* is the *sine* of the angle SOG. In like manner, A*e* is the sine of AOS L*d* of LOP, and R*e* of ROP. In this figure, DPD′O, may represent a section of a vessel of water, GO a ray of light incident at the point of the surface O, which, instead of continuing its course through the water to L, will be bent from that direction, and approach the perpendicular to the surface drawn through O, the point of incidence, and take the course OR. G*b* then is the sine of the angle of incidence, and R*e* or A*e*, which is equal thereto, is the sine of the angle of refraction. These lines, as stated in the text, bear a fixed proportion to each other in each medium, so that, either being given, and the medium designated, the other can be instantly inferred.

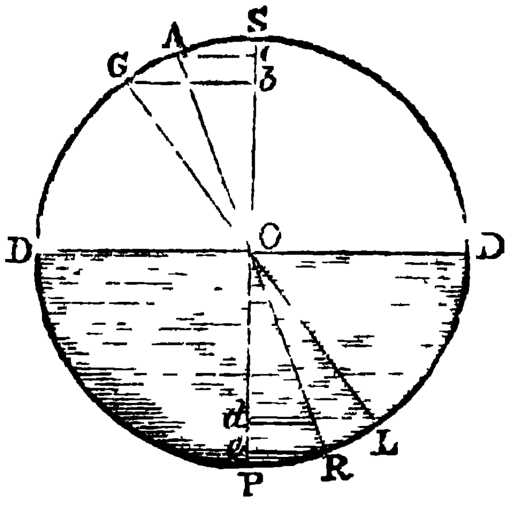

Fig. 43.

A straight line is said to be a *tangent* to a circle when it touches the circumference only on one point, and this from the nature of the circle it cannot do, unless it make a right angle with the radius at the point of contact. AX, perpendicular to the radius SB, is a tangent to the circle BYTU (fig. 22, page 95). The tangent (by its definition) coincides with an infinitely small portion of the curve to which it is applied; and, as a tangent may be found for every conceivable point of the curve, it is evident that a curve may practically be considered as consisting of an infinite number of small straight lines, tangents to it. To assist the reader's imagination in embracing this principle, let him reflect on the possibility of his constructing an approach to a regular curved figure, say a semicircle, with a number of small straight lines of equal length: the shorter and the more numerous his straight lines, the nearer will he be to imitating the desired form. Thus, in bridge-building, the flat faces of bricks are arranged together to form the cylindrical or otherwise curved intrados, or lower face of the arch. Apply this to what is said (page 7) of spherical lenses.

Every one is familiar with the common method of describing a circle by making a straight line or interval revolve on a plane surface round one of its extremities. Hence we define the circle as a plane figure bounded by one curved line of such a nature, that all points in it are equally distant from a certain point within the figure called the *centre.* In like manner, generalizing the directions given in the text for constructing an ellipse (page 23), we learn that an ellipse is a plane figure bounded by one curved line, such that the respective sums of the distances of any two points in it from two fixed points within the figure, called *foci*, are equal. The line joining the foci, and terminating both ways in the circumference, is the *major axis:* the middle point of this line is the centre of the ellipse, the distance of which from either focus is the *eccentricity* of the ellipse. The line drawn through the centre at right angles to the major axis, and terminating in the circumference, is the *minor axis.* In fig. 22, page 95, the lines SB, SC, SD, SE, SF, SI, SK, are each a radius-vector of the ellipse BCDEFIKL, and the several spaces BSC, CSD, DSE, &c., are equal.—*Trans.*

The Moon.

The assertion in the text, page 66, that the moon's rays possess no chemical efficacy, must be received with some limitation; in proof of which, we need but advert to the daguerreotype, with which pictures can be produced by moonlight as well as in sunshine, though in the former case the operation occupies twenty minutes, in the latter from three to five. But even with this restriction, the arguments against the imagined influences of the moon on animal and vegetable life will be amply conclusive. Besides the cases alluded to in the body of the work, the reader will no doubt have recollected others, in which popular prejudice has attributed to the moon a strange and mysterious control over the animal economy. Epilepsy and insanity were long supposed to evince her baleful influence. This opinion no longer obtains general credence amongst medical men, though it must be owned it has never been confuted in the only way such questions can receive a satisfactory solution, namely, by statistical observations on an ample scale. We may, however, remark, that even were it thoroughly established that exacerbations of insanity, and other chronic maladies of the brain, recur at regular intervals of twenty-nine or thirty days, it would by no means follow from thence that the relation of these intervals to the time of the moon's revolution in her orbit, was any other than that of mere accidental coincidence. There is, on the other hand, abundant proof of the adaptation of the human constitution to the period of the earth's rotation on her axis; and, as we see in tertian and quartan fevers, a period of three and four times twenty-four hours is required to evolve the symptoms of those diseases, so there is nothing, on the other hand, to be urged *à priori* either for or against the probability, that other phenomena of the healthy or diseased economy should need thirty times twenty-four hours for their development. "That period of twenty-four hours formed by the regular rotation of our earth," says Hufeland, "in which all its inhabitants partake, is particularly distinguished in the physical economy of man: this regular period is apparent in all diseases. . . . It is, as it were, the unity of our natural chronology."

Nothing indicative of the presence of water is discoverable on the moon's surface. This is in strict keeping with the fact of her possessing no atmosphere, or at least none at all comparable with that of the earth. Some little covering of the kind she may have, but its density at the maximum cannot amount to 1-968ths of our air, and may be greatly below this. Under the faint pressure of so rare an atmosphere as this, water would rapidly be converted into vapour, and thus the moon would be invested with a misty covering.

Where there is neither water nor air, there cannot be plants with leaves to respire the latter, nor roots to imbibe the former. There cannot be animals with blood or lungs, with digesting or secreting apparatus, &c.

For want of a refractory medium, light cannot be diffused over the moon's surface. The brightness of direct irradiation must stand in immediate and unmitigated proximity to total darkness, save in as far as this is imperfectly obviated by lateral reflection.

Sound is caused by the disturbance of an elastic medium, and the production of waves which impinge on the organs of hearing. Saussure found sound greatly diminished on the summit of Mont Blanc. It altogether ceases in a vacuum.

Moisture is essential to the functions of smell and taste.

These considerations assuredly do not warrant us in concluding that the moon is uninhabited, but they tend to show that, with our very limited knowledge of our own minute fraction of the vast universe, it is utterly impossible for us to imagine with what sort of beings the Creator may have peopled the nearest planet to our globe. Yet there have been men of science who have seen in the moon works similar to those of human hands; and practical astronomers have reported the existence on the moon's surface of architectural monuments, of works like those constructed by man; no being bearing any conceivable resemblance to whom can possibly exist on that planet!—*Trans.*

Shooting Stars.

No account of the solar system can well be considered complete without some mention of a class of bodies that have, for some years past, strikingly arrested the attention of the multitude, as well as of astronomers. We mean SHOOTING STARS, of which, from about the year 1831, dense showers have been annually noticed about the 13th of November. The observed parallax of several shooting stars proves them to exist at a height far exceeding that of the sensible limits of our atmosphere, thus annihilating the theory that has hitherto regarded them as produced by the incandescence of gases in the air. Comparative observations made in 1823 at Breslau, Dresden, Leyden, Brieg, Gleiwitz, &c, by Professor Brandes and some of his pupils, assigned to certain of these so-called meteors, an elevation of no less than 500 English miles. The apparent velocity of some of them has amounted to thirty-six miles per second, almost double that of the earth's motion in the ecliptic. Now, should half this be supposed an illusion, arising from the opposite motion of the earth, there would still remain a velocity of eighteen miles per second, which exceeds that of all the superior planets except the earth. The usual direction of these stars makes it manifest, independently of other proof, that, though they may pass into our atmosphere and take fire there, at least they have not their origin in it. The more usual course of shooting stars appears diametrically opposed to the earth's motion in her orbit.

In 1799, a shower of stars was observed in America by Von Humboldt, in Greenland by the Moravian brethren, and by several persons in Germany. This was on the night of the 11th and 12th of November.

In 1831 and subsequent years, the phenomenon was again observed at the same period of the year in America and elsewhere; it was particularly conspicuous in the former continent on the night of the 12th and 13th of November, 1833. The stars were so numerous, and appeared in so many parts of the heavens at once, that their numbers could only be very roughly approximated to. The Boston observer compared them to half the number of flakes seen in the air during a common fall of snow. When their number was greatly diminished, he counted 650 stars in fifteen minutes, though confining his observations to a zone less than the tenth of the visible horizon. This number, he states, was but two-thirds of the real amount, which would thus be 975, and for the whole visible horizon 9,750. This would give 39,000 stars per hour. Now the phenomenon lasted more than seven hours, therefore the number of stars passing in sight of Boston was more than 273,000; for it must be recollected, that this calculation is founded on observations which were not made till the phenomenon was considerably on the decline.

It is worthy of remark that, with a few exceptions, these showers all appeared to proceed from a common centre, the position of which has been uniformly in nearly the same point of the heavens, viz. in some part of the constellation of Leo. The principal exhibition has at all times, and in all places, occurred between midnight and sunrise, and reached its maximum between three and four o'clock.

The 13th of November, 1835, a large and brilliant meteor, observed by M. Millet Daubenton, fell near Belley, departement de l'Ain, and burned a barn; on the same night M. Delezence observed, at Lille, a falling star exceeding Jupiter in brilliancy. It left behind it a train of sparks exactly resembling those produced by a squib.

A very remarkable meteor was observed at Dieppe and Paris on the 19th August, 1847, with sufficient precision to admit of calculation of the elements of its orbit in space. If it had come from the nearest fixed star, it must have taken up 37,340 years in its passage, if we suppose that star to have a parallax of 1″.

The theory of these surprising phenomena is not yet established. Arago thinks that everything tends to confirm the existence of a zone consisting of millions of small bodies, whose orbits meet the plane of the ecliptic near the point occupied by the earth in November,—a new planetary world, in fact, which has just begun to be revealed to us.

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